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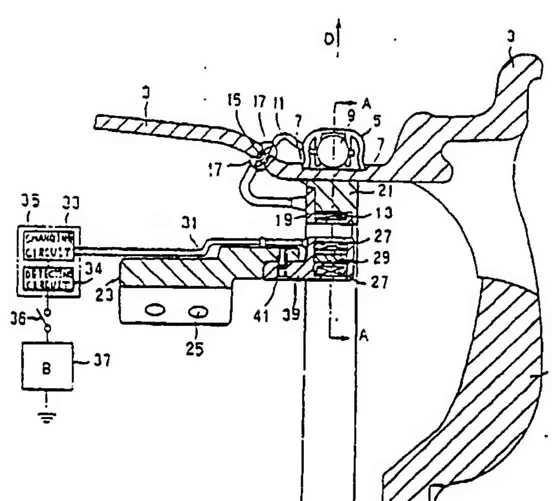
(54) Tire pressure detecting apparatus for vehicle.

(57) A tire pressure detecting portion includes a housing, provided within the tire, within which a piezoelectric element is provided so as to be deformed by the tire pressure, whereby the capacity of said piezoelectric element is changed in accordance with its deformation. The piezoelectric element is electrically connected with a first coil disposed within said tire. The first coil is electromagnetically coupled with an excitation coil and a receiving coil, both of which are provided in the vehicle. The excitation coil is electrically connected with an oscillator for supplying the excitation coil with an excitation voltage whose frequency is changed with a predetermined range including a resonant frequency. The receiving coil is electrically connected with resonant frequency determining means. The resonant frequency determining means determines that the received voltage has the resonant frequency. As a result of such determination, pressure determining means determines the corresponding tire pressure based on a data map showing the relationship between said resonant frequency and said tire pressure.

FIG.1



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FIELD OF THE INVENTION

The present invention relates to an apparatus for detecting tire pressure.

BACKGROUND OF THE INVENTION

According to the conventional arts, it is known that there are three types apparatus for detecting the tire pressure.

First type of apparatus, which is disclosed in the United States Patent No.4,567,459, includes a pressure detecting circuit which is mounted in the tire for generating an electrical signal indicative of the tire pressure. The pressure detecting circuit is comprised of various electronic devices for modulating the generated electrical signal by frequency modulation. The modulated electrical signal is transferred to the vehicle body by electromagnetic coupling.

Second type is disclosed in page 15 of AUTOMOTIVE ELECTRONIC NEWS which is published on June 26, 1989. According to this journal, it is disclosed that a pressure detecting circuit for detecting the tire pressure is mounted in the tire. The pressure detecting circuit includes a radion transmitting circuit for transmitting the detected signal to the body of the vehicle.

Third type is disclosed in Toku-Kai-Sho 61-141,098 (Japanese laid open patent application). The apparatus includes a semiconductor pressure sensor and a LC resonant circuit both of which are mounted in the tire. According to this apparatus, the tire pressure is changed to the electric resistance of the semiconductor pressure sensor. Since the Q value of the LC resonant circuit is changed in accordance with the resistance of the semiconductor sensor, the tire pressure is detected by detecting the Q value.

However, the above described conventional apparatuses have problems on their durability because the electronic devices or the circuit elements are mounted in the tire and therefore exposed in the very severe condition, for example, high temperature and high vibration. Namely, their characteristic are easily changed and deteriorated under such a condition. For example, the Q value of the LC resonant circuit disclosed in the above Toku-Kai-Sho 61-141,098 is easily changed by the other factors except the resistance of the semiconductor pressure sensor.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an tire pressure detecting apparatus which is capable of properly detecting the tire pressure under the sever condition.

For the purpose of achieving the above object, a tire pressure detecting apparatus for detecting a tire pressure of a vehicle, comprises the following elements: namely, pressure-capacity transforming means, provided within said tire, for transforming the tire pressure change into electrostatic capacity change;

resonant signal producing means, electrically connected with said pressure-capacity transforming means within said tire, for producing a resonant electric signal having a resonant frequency in accordance with the capacity change generated from said pressure-capacity transforming means;

voltage supplying means, provided in said vehicle, for supplying said resonant signal producing means with alternating voltage whose frequency is changed within a predetermined range including said resonant frequency;

resonant signal receiving means, provided in said vehicle, for receiving said resonant electric signal produced from said resonant signal producing means; and

pressure detecting means, provided in said vehicle, for detecting the tire pressure based on said received resonant electric signal.

According to the present invention, other structure can be provided as follows: namely, first pressure-capacity transforming means, provided within said tire, for transforming the tire pressure change into electrostatic capacity change;

second pressure-capacity transforming means, provided within said tire, for transforming the tire pressure temperature into electrostatic capacity change;

first resonant signal producing means, electrically connected with said first pressure-capacity transforming means within said tire, for producing a first resonant electric signal having a first resonant frequency in accordance with the capacity change generated from said first pressure-capacity transforming means;

second resonant signal producing means, electrically connected with said second pressure-capacity transforming means within said tire, for producing a second resonant electric signal having a second resonant frequency in accordance with the capacity change generated from said second pressure capacity transforming means;

first voltage supplying means, provided in said vehicle, for supplying said first resonant signal producing means with alternating voltage having at least said first resonant frequency;

second voltage supplying means, provided in said vehicle, for supplying said second resonant signal producing means with alternating voltage having at least said second resonant frequency;

first resonant signal receiving means, provided in said vehicle, for receiving said first resonant

electric signal produced from said first resonant signal producing means;

second resonant signal receiving means, provided in said vehicle, for receiving said second resonant electric signal produced from said second resonant signal producing means;

pressure detecting means, provided in said vehicle, for detecting the tire pressure based on said first received resonant electric signal; and

temperature detecting means, provided in said vehicle, for detecting the tire temperature based on said second received resonant electric signal.

According to the first-described structure of the present invention, the tire pressure change is transformed to the electrostatic capacity change by the pressure-capacity transforming means. Then, this electrostatic capacity change is transformed to the resonant electric signal having the resonant frequency by the resonant signal producing means. In this case, a resonant circuit is formed by only the pressure-capacity means or a combination of pressure-capacity means and the resonant signal producing means. So, the electric circuit within the tire can be very simple and durable. As a result, the semiconductor sensor or complex electronic circuit which is not resistant to the severe condition within the tire. Therefore, the resonant frequency is stable detected regardless of such a severe condition according to the present invention.

According to the second described structure of the present invention, the tire pressure can be compensated in accordance with the corresponding tire temperature because the tire pressure and the corresponding tire temperature are simultaneously detected by using the first and second resonant frequencies.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a sectional view showing a whole structure of a first embodiment according to the present invention;

Fig. 2 is a sectional view of a portion shown by A-A line in Fig. 1;

Fig. 3 is a schematic view showing a fixing condition of a pressure detecting portion of the first embodiment;

Fig. 4 is a plan view of the pressure detecting portion shown in Fig. 3;

Fig. 5 is a detail sectional view of the pressure detecting portion;

Fig. 6 is a left side view of the pressure detecting portion shown in Fig. 5;

Fig. 7 is a sectional view of a portion shown by E-E line in Fig. 5;

Fig. 8 is an electrical diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 9 is a characteristic diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 10 is an electrical diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 11 is an electrical diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 12 is an electrical diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 13 is an electrical diagram for explaining the operation principle of the first embodiment according to the present invention;

Fig. 14 is a block diagram of the first embodiment according to the present invention;

Fig. 15 is a characteristic diagram showing an electric current i_1 which is used in the first embodiment according to the present invention;

Fig. 16 is a characteristic diagram showing an electric current i_2 which is used in the first embodiment according to the present invention;

Fig. 17 is a block diagram of an electronic control unit in first embodiment according to the present invention;

Fig. 18 is a flow chart showing a program carried out by the electronic control unit shown in Fig. 17;

Fig. 19 is a sectional view showing a structure of a second embodiment according to the present invention;

Fig. 20 is an electric diagram of the second embodiment according to the present invention;

Fig. 21 is a characteristic diagram showing a relationship between the phase difference and the resonant frequency in the second embodiment according to the present invention;

Fig. 22 is a diagram showing a relationship between the excitation voltage and the received voltage in the second embodiment according to the present invention;

Fig. 23 is a characteristic diagram showing a relationship between the received voltage and the frequency, and a relationship between the phase difference and the frequency in the second embodiment according to the present invention;

Fig. 24 is a characteristic diagram showing a relationship between the air pressure and the resonant frequency in the second embodiment according to the present invention;

Fig. 25 is a block diagram showing a configuration of a phase difference control circuit of the second embodiment according to the present invention;

Fig. 26 is a diagram showing waveforms in various points illustrated in Fig. 25;

Fig. 27 is a block diagram showing a configuration of the other phase difference control circuit of the second embodiment according to the present invention;

Fig. 28 is a diagram showing waveforms in various points illustrated in Fig. 27;

Fig. 29 is an electric diagram showing a configuration of a third embodiment according to the present invention;

Fig. 30 is a characteristic diagram showing a relationship between a resonant frequency and temperature in a resonant circuit of the third embodiment according to the present invention;

Fig. 31 is a detail sectional view of the pressure detecting portion in the third embodiment according to the present invention;

Fig. 32 is a sectional view of a wheel to which the third embodiment are applied:

Fig. 33 is a sectional view of a wheel to which the third embodiment are applied;

Fig. 34(a) is a characteristic diagram showing a relationship between a frequency and a phase difference in a temperature detecting circuit in the third embodiment according to the present invention;

Fig. 34(b) is a characteristic diagram showing a relationship between a frequency and an input-output ratio of the receiving voltage to the excitation voltage in a temperature detecting circuit in the third embodiment according to the present invention;

Fig. 35(a) is a characteristic diagram showing a relationship between a frequency and a phase difference in a pressure detecting circuit in the third embodiment according to the present invention;

Fig. 35(b) is a characteristic diagram showing a relationship between a frequency and an input-output ratio of the receiving voltage to the excitation voltage in a pressure detecting circuit in the third embodiment according to the present invention;

Fig. 36 is a characteristic diagram showing a relationship between a resonant frequency and a tire temperature in the third embodiment according to the present invention;

Fig. 37 is a characteristic diagram showing a relationship between a resonant frequency and a tire pressure in the third embodiment according to the present invention;

Fig. 38 is a flow chart showing a program carried out by electronic control unit in the third embodiment according to the present invention;

Fig. 39 is a diagram showing a electric configuration of a fourth embodiment according to the present invention;

Fig. 40 is a sectional view of a wheel to which the fourth embodiment are applied;

Fig. 41(a) is a characteristic diagram showing a relationship between a frequency and a phase difference in the fourth embodiment according to the present invention;

Fig. 41(b) is a characteristic diagram showing a relationship between a frequency and an input-output ratio the receiving voltage to the excitation voltage in the fourth embodiment according to the present invention;

Fig. 42 is a sectional view of a pressure detecting portion in a fifth embodiment according to the present invention;

Fig. 43 is a sectional view of an enlarged portion shown in Fig. 42;

Fig. 44 is a plan view showing a negative part of a connecting portion in the fifth embodiment according to the present invention;

Fig. 45 is a plan view showing a positive part of a connecting portion in the fifth embodiment according to the present invention;

Fig. 46 is a plan view form the direction F illustrated in Fig. 47;

Fig. 47 is a sectional view showing a fixing structure of a bobbin used in the fifth embodiment according to the present invention;

Fig. 48 is a diagram showing an electric configuration of a fifth embodiment according to the present invention;

Fig. 49 is a diagram showing a electric configuration of a sixth embodiment according to the present invention;

Fig. 50 is a diagram showing waveforms in the sixth embodiment according to the present invention;

Fig. 51 is a diagram showing waveforms in the sixth embodiment according to the present invention;

Fig. 52 is a sectional view showing one condition of a pressure detecting portion in the sixth embodiment according to the present invention;

Fig. 54 is a sectional view showing the other condition of a pressure detecting portion in the sixth embodiment according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, the preferred embodiments are explained below with reference to the figures.

(First embodiment)

In Fig. 1, a reference numeral 1 designates a wheel to which a rim 3 of a tire is connected. Reference numeral 5 designates a case which is made of elastic material such as beryllium cupper. Both ends of the case 5 is fixed in a cutting portion

7 of the rim 3 by elasticity of the case 5, or other fixing means such as welding or as adhesive. Within the case 5, a pressure detecting portion 9 is provided so that the pressure detecting portion 9 does not touch the rim 3. Namely, as shown in Fig. 3, the pressure detecting portion 9 is supported in a space within the case 5 by a pair of bent portions 5a which are integrally formed with the case 5 and then bent inwardly. In this case, the bent portions 5a hold cut portions 73 formed on both sides of the pressure detecting portion 9 by using their elasticity. Both input and output terminals of the pressure detecting portion 9 are electrically connected through a lead wire 11 and a connecting member 15 to a first coil 13. The lead wire 11 is supported by a harness member 43 as shown in Fig. 4. The connecting member 15 comprises a pair of wires, which are connected with the lead wire 11, and a insulating member such as glass which covers the pair of wire. The connecting member 15 is fixed to the rim 3 with a rubber member 17 so that the connecting portion between the lead wire and the connecting member 15 is sealed with the rubber member 17. The first coil 13 is wound on a bobbin 19 whose section forms a letter L shape. The bobbin 19 is set on a stay 21 by welding or adhesive, which is coupled to the rim 3. Reference numeral 27 designates a second coil which is wound on an iron core 29 and accommodated within a case 39 which is made of nonmagnetic material such as plastic, material having a high electric resistance. The case 39 is connected to a stay 23 by a bolt 41. The stay is fixed to a vehicle body, which is not shown in the drawings, by using a fixing holes 25 and bolts. According to the above described structure, the second coil 27 faces the first coil 13 as shown in Fig. 1 so as to obtain an electromagnetic coupling with the first coil 13. The second coil 27 is electrically connected through a lead wire 31 with an electronic control unit (hereinafter called ECU) 35 which includes a frequency change circuit 34 and a resonant frequency detecting circuit 35. The ECU is electrically connected through an accessory-key switch 36 with a battery 37 of the vehicle.

In Figs. 1 and 2, when the tire having the wheel 1 and the rim 3 rotates in a vertical direction to the surface of Fig. 1, namely in a direction shown by an arrow B or C in Fig. 2, a centrifugal force occurs in a direction shown by an arrow D in Fig. 1. In this case, the pressure detecting portion 9 is disposed within the case 5 in an appropriate direction that a piezoelectric device does not have an effect of that centrifugal.

The detail structure of the pressure detecting portion 9 is explained with reference to Fig. 5 through Fig. 7. In Fig. 5, the pressure detecting portion 9 comprises a cylindrical housing 45 within which a low pressure chamber 69 and a pressure introducing chamber 71 are formed by a piezoelectric assembly 53a and a circular cap 65. The cylindrical housing 45, which is made of aluminum or stemless steel, has a circular step portion 47 therein. Reference numeral 49 designates a circular diaphragm which is made of elastic material such as stemless steel. A fixing portion 51 of the diaphragm 49 is fixed to the step portion 47 by welding or adhesive so as to form the low pressure chamber 69 within which the pressure is close to vacuum. The diaphragm 49 is adhered to a piezoelectric assembly 53a which includes a circular piezoelectric element 53, which is made of a ceramic material, and a pair of circular electrodes 55 and 56 which are formed on both sides of the piezoelectric element 53 by heat treatment of silver paste. The thickness of the piezoelectric element 53 is decided in the range between 0.1mm through 0.2mm. Both electrodes 55 and 56 are electrically connected through lead wired 57a and 59a with wires 57 and 59, respectively. Both wires 57 and 59 are inserted in a insulating member 61 and electrically connected with the lead wire 11. The insulating member 61 is fixed to the housing 45 with a rubber seal member 63. The cap 65, which is made of aluminum or stemless steel, is coupled to the housing 45 by welding or adhesive so as to form the pressure introducing chamber 71 between the piezoelectric assembly 53a and the cap 65. In order to introduce the tire pressure into the pressure introducing chamber 71, a plurality of pressure introducing holes 67 are formed through the cap 65.

The operation principle is explained with reference to Fig. 8 through Fig. 13. Fig. 8 shows a RLC series resonant circuit in which a resistance 75, a coil 77 and a condenser 79 are connected in series. In this circuit, if the frequency of the alternating power source 81 is changed, the electric current flowing through the circuit is changed in response to the change of the frequency as shown in Fig. 9. Namely, the electric current is maximal when the frequency f is resonant frequency f_1. The similar characteristic shown in Fig. 9 occurs in each circuit illustrated in Fig. 10 through Fig. 13. In Fig. 10, a condenser is connected parallel with a RLC series resonant circuit in which a resistance 83, a coil 85 and a condenser 87 are connected in series. Fig. 11 shows an electric code of piezoelectric element 53 which has an impedance including resistance, inductance and capacitance. Therefore, the piezoelectric element 53 resonates at a resonant frequency which is determined by its impedance, especially its capacitance. In this case, the capacitance of piezoelectric element 53, namely its resonant frequency, is changed in accordance with the change of the tire pressure which is applied to

the piezoelectric element 53. Accordingly, the tire pressure is detected by detecting the resonant frequency of the piezoelectric element 53 or a resonant circuit using the piezoelectric element 53. For the purpose of detecting the resonant frequency of the piezoelectric element 53 or the like, a resonant circuit shown in Fig. 13, in which the piezoelectric element 53 is connected with a coil 93, is used according to the first embodiment of the present invention.

In consideration of the above described principle, the electric circuit of the first embodiment is formed as shown in Fig. 14. The circuit includes two separate circuit. First circuit C1, which includes the piezoelectric element 53 and the first coil 13, is provided in the tire as shown in Fig. 1. The first circuit C1 is electrically equivalent to the resonant circuit shown in Fig. 13. The second circuit C2, which includes the second coil 27 and the ECU 35, is provided in the body of the vehicle. In this configuration, since there is the electromagnetic coupling between the first coil 13 and the second coil 27, when the alternating voltage is applied to the second coil 27, the alternating voltage is applied to the second coil 27, the alternating voltage is applied to the first circuit C1 by the magnetic coupling. Accordingly, as the frequency of the alternating voltage is changed by the frequency change circuit 33, the voltage frequency of the first circuit C1 is also changed in a way that the first circuit resonates at a resonant frequency f_1 as shown in Fig. 15. The resonant frequency f_1 is detected through the first coil 13 and the second coil 27 by the resonant frequency detecting circuit 34. In this case, the induced current i_2 of the second coil 27 is changed as shown in Fig. 16 in response to the frequency change. As explained above, because the resonant frequency f_1 of the first circuit C1 is changed by the change of the tire pressure, the tire pressure is obtained by detecting the resonant frequency f_1.

In Fig. 17. the detail configuration of the ECU 35 is illustrated. The frequency change circuit 33 is a variable frequency oscillator which changes the oscillating frequency within a predetermined range (including the resonant frequency f_1) at a predetermined interval. The resonant frequency detecting circuit 34 includes a low resistance r connected to the second coil 27, a amplifier 34a, which has high input impedance for amplifying the voltage drop in the low resistance r, a detector 34b for detecting the output voltage of the amplifier 34a, a smoothing circuit 34a for smoothing the detected voltage, an A-D converter for converting the smoothed direct current voltage into a digital signal and a microcomputer 34e for processing the converted digital signal and then computing a tire pressure. Accordingly, the digital signal is proportional to the average value of the electric current i_2 flowing the second coil 27.

In view of the above described configuration, an operation of the first embodiment of the present invention is explained in detail below. In Fig. 1, when the accessory key-switch 36 is turned on by a driver, the direct current voltage is supplied to the circuit from the battery so that the frequency change circuit 33 supply the alternating voltage to the second coil 27. As a result, the induced current occurs in the first circuit C1 by electromagnetic coupling. In the meantime, when the tire pressure is changed the pressure of the pressure introducing chamber 71 is changed through the pressure introducing holes 67. By this pressure change, the diaphragm 49 is deformed because the pressure of the low pressure chamber 69 maintains a constant pressure. According to the first embodiment, since the pressure of the low pressure chamber 69 is almost vacuum, it maintains the constant pressure regardless the temperature change. As a result, the piezoelectric element 53 is deformed so as to change its impedance especially its capacitance. This impedance change causes a resonant frequency change in the first circuit C1. The resonant frequency change is detected by the resonant frequency detecting circuit 34. Namely, the microcomputer 34e determined the tire pressure based on such a resonant frequency. An operation carried out by the microcomputer 34e is shown in Fig. 18. In a step 101, induced electric current i_2 is inputted through the A-D converter 34d. Then, it is determined whether the inputted electric current is fewer than the previous one in a step 103. If so, after the predetermined interval set in a step 105, the electric current i_2 is again inputted in a step 107. If not, the program returns to the step 101. Then, in a step 108, it is determined whether the electric current i_2 inputted in the step 107 is larger than the electric current i_2 inputted in the step 101. If not, the program returns to the step 101. If so, the electric current i_2 inputted in the step 107 is regarded as the minimal value i_{2min} shown in Fig. 16, then, the program proceeds to a step 111 in which the resonant frequency corresponding to such current is obtained from a first data map. The first data map specifies a relationship between minimal electric current i_{2min} in the second circuit C1 and the resonant frequency corresponding to such a minimal electric current i_{2min}. Then, the tire pressure corresponding to the obtained resonant frequency is obtained from a second data map in a step 113. The second data map specifies a relationship between the resonant frequency and the tire pressure. Both first data map and second data map are stored in ROM in the microcomputer 34e. The, the obtained tire pressure is outputted from the microcomputer 34e in a step 115. The, in a

step 117, when the predetermined interval lapses, the program returns to the step 101.

According to the above described first embodiment, the pressure can be accurately obtained regardless of the severe condition because the piezoelectric element 53 and the first coil 13, both of which are provided in the tire to form the first circuit C1, have a simple and durable structure to the sever condition such as high temperature.

(Second embodiment)

A second embodiment of the present invention is explained below with reference to Fig. 19 through Fig. 29. According to the second embodiment, an excitation coil 99 and a receiving coil 101 are provided in the vehicle body for the purpose of obtaining the magnetic coupling with the first coil 13 as shown in Fig. 19 and Fig. 20. In Fig. 19, the excitation coil 99 and the receiving coil 101 are wound with iron cores 103 and 105, respectively and provided in a case 95 which is made of non-magnetic material such as plastic, material having a high electric resistance.

In Fig. 20, the excitation coil 99 is electrically connected with the frequency change circuit 33. The receiving coil 101 is electrically connected with the resonant frequency detecting circuit 340. In addition to the resonant frequency detecting circuit 340, a phase difference control circuit 200 is electrically connected with the frequency change circuit 33 and the receiving coil 101 so that the phase difference between the excitation voltage V_1 and the receiving voltage v_2 becomes $\pi/2$. In this circuit, the resonant frequency detecting circuit 340 is connected to the phase difference control circuit 200 in a way that it detects the frequency of the receiving voltage V_2 when the phase difference between the excitation voltage v_1 and the receiving voltage v_2 becomes $\pi/2$.

The operation of the circuit shown in Fig. 20 is explained below. The first coil 13 in the first circuit C1 is excited by the electromagnetic coupling when the excitation voltage v_1 is applied to the excitation coil 99. The, the receiving voltage v_2 is generated through the receiving coil 101. In this case, when the frequency of the excitation voltage V_1 is equal that of the resonant frequency of the first circuit C1, the phase difference between the excitation voltage V_1 and the receiving voltage V_2 becomes $\pi/2$ as shown in Fig. 22. According to the second embodiment, the phase difference control circuit 200 controls the phase difference between the excitation voltage v_1 and the receiving voltage v_2 so that it maintains $\pi/2$. So, as shown in Fig. 21, the frequency of the receiving voltage V_2 detected as a resonant frequency fr_1 or fr_2 by the resonant frequency detecting circuit 340 when the phase difference between the excitation voltage V_1 and the receiving voltage V_2 becomes $\pi/2$, namely when the first circuit C1 is in a resonant condition. When such a resonant condition, the receiving voltage V_2 becomes a maximum value as shown in Fig. 23. As a result, a S/N ratio of the receiving voltage V_2 becomes high in such a condition so that the resonant frequency of the receiving voltage V_2 can be easily detected. The, the tire pressure is detected based on the relationship between the resonant frequency fr of the receiving voltage V_2 as shown in Fig. 24. The tire pressure is proportional to the resonant frequency fr of the receiving voltage V_2. As described above, because the resonant frequency can be detected by using the phase difference between the excitation voltage V_1 and the receiving voltage V_2, an inaccurate detection, which would result from the change of the receiving voltage V_2 by noise, can be prevented.

The detail configuration and the operation of the phase difference control circuit 200 is explained below with reference to Fig. 25 and Fig. 26. In Fig. 25, a voltage control oscillator 330, which works as the frequency change circuit 33, is designed to change its frequency within a predetermined range including the resonant frequency of the first circuit C1. The excitation voltage V_1 from the voltage control oscillator 206 is supplied to the excitation coil 99 so as to excite the first coil 13 by electromagnetic coupling. On the other hand, the receiving coil 101 is connected to a comparator 201 which converts the sine-wave receiving voltage V_2 into the rectangular voltage V_k. The rectangular voltage V_k is compared to the excitation voltage v_1 in a exclusive or gate 202. The output voltage V_g of the exclusive gate 202 becomes low level when the rectangular voltage V_k is equal to the excitation voltage V_1. On the other hand, the output voltage V_g of the exclusive or gate 202 becomes high level when the rectangular voltage V_k is different from the excitation voltage V_1. The output voltage V_g is converted into the direct current voltage V_f by a low-pass filter 203. The direct current voltage V_f is compared to the reference voltage V^r which is generated from a reference voltage generator 204. A control voltage generator 205 generates the output voltage V_c so that the voltage difference between the direct current voltage V_f and the reference voltage V_r is zero. In this circuit, when the phase difference between the rectangular voltage V_k and the excitation voltage V_1 is $\pi/2$, the duty ratio of the output voltage V_g of the exclusive or gate 202 becomes value V_{gx} of the output voltage V_g of the exclusive-or gate 202. Accordingly, when the reference voltage V_r is one half of the output voltage V_g of the exclusive-or gate 202, the oscillating frequency of the excitation voltage V_1 is equal to the resonant frequency of the first circuit C1 is in

a resonant condition.

The other example of the phase difference circuit 200 is explained below with reference to Fig. 27 and Fig. 28. In Fig. 27, the receiving voltage V_2 is converted into the rectangular voltage V_k in a comparator 303. The rectangular voltage V_k is inputted to a input terminal D of a D flip-flop 302. A clock-pulse input terminal of D flip flop 302 is connected to a phase shifter 305 which generates the signal voltage V_{ck} whose phase is different from that of the excitation voltage V_1 by $\pi/2$. when the phase of the rectangular voltage V_k is leading to the signal voltage V_{ck}, the output voltage V_g of the D flip-flop 302 is high level. On the other hand, when the phase of the signal voltage V_{ck} is leading to that of the rectangular voltage V_k, the output voltage V_g of the D flip-flop is low level. The output voltage V_g of the D flip-flop 302 is converted to the direct current voltage by the low-pass filter 303 and then, is inputted to the voltage control oscillator 330. As shown in Fig. 28, the oscillating frequency of the voltage control oscillator 330 increases as the output voltage V_c of the low-pass filter 303 increases. In the operation of this circuit, the phase difference between the rectangular voltage V_k and the signal voltage V_{ck} becomes zero. Accordingly, the phase difference between the rectangular voltage V_k and the excitation voltage V_1 becomes always $\pi/2$ because the phase of the signal voltage V_{ck} is leading to the phase of the excitation voltage V_1 by $\pi/2$. As a result, the oscillating frequency of the voltage control oscillator 330 is equal to the resonant frequency of the first circuit C1.

(Third embodiment)

The third embodiment of the present invention is explained below with reference to Fig. 29 through Fig. 38. According to the third embodiment, a temperature compensating function is added to the apparatus described in the second embodiment.

In Fig. 29, reference numeral 270 designates a pressure detecting circuit which is identical with the circuit in the above second embodiment as shown in Fig. 20. Reference numeral 280 designates a temperature detecting circuit whose configuration is similar to the pressure detecting circuit 270. Namely, the temperature detecting circuit 280 includes a first circuit C10, which is provided in the tire of the vehicle, and a second circuit C20 which is provided in the vehicle body. A piezoelectric element 54 of the first circuit C10 electrically connected with a first coil 14 in order to form a resonant circuit. In this case, the piezoelectric element 54 is provided in the tire for detecting the tire temperature instead of the tire pressure. Since the capacity of the piezoelectric element 54 is changed in accordance with the tire temperature, the resonant frequency of the first circuit C10 is changed in accordance with the tire temperature. A excitation coil 281 of the second circuit C20 is electrically connected with a frequency changing circuit 332 for supplying the excitation coil 281. A receiving coil 282 is electrically connected with a frequency detecting circuit 342. Both coils 281 and 282 are electromagnetically coupled to the resonant coil 14. The difference between the pressure detecting circuit 270 and the temperature detecting circuit 280 is that the temperature detecting circuit 280 produces the resonant frequency f_T indicative of the tire pressure, while the pressure detecting circuit 270 produces the resonant frequency f_p indicative of the tire pressure. The pressure detecting circuit 270 and the temperature detecting circuit 280 are electrically connected with the microcomputer 350 so that both the resonant frequency f_p and the resonant frequency f_T inputted in the microcomputer 350 which computes the tire pressure and the tire temperature. A ROM 103 of the microcomputer 350 stores a first data map, which indicates a relationship between the resonant frequency f_T and the tire temperature, and a second data map, which indicates a relationship between the resonant frequency f_p and the tire pressure. The first data map is previously made by measuring the various tire temperature and the corresponding resonant frequency f_T within a predetermined temperature range such as -30°C through 140°C as shown in Fig. 36. The measuring results is indicated in Fig. 30 in which the resonant frequency f_T decrease in proportion to the tire temperature. The second data map is previously made by measuring the tire pressure and the corresponding resonant frequency f_p at various temperature which covers a minimum temperature $T_C - n_\Delta T$ through a maximum temperature $T_0 + n._\Delta T$ (n is a integral number) within a predetermined pressure and temperature range as shown in Fig. 37. In this case, the deviation value $_\Delta T$ is 1°C for instance. The microcomputer 350 is electrically connected to an indicator 105 for indicating the tire pressure and the tire temperature to the driver of the vehicle.

Installation structure for each element of the above described circuits are explained below with reference to Fig. 31 through Fig. 33. In Fig. 31, the same reference numeral, which are used in Fig. 5, designates the same structures shown in Fig. 5. According to the third embodiment, the pressure detecting portion 109 include a structure for installing the piezoelectric element 54 for detecting the tire temperature. In Fig. 31, a hollow portion 45a is formed within the hosing 45. A diaphragm 149 is fixed to the inside wall of the hollow portion 45a together with the piezoelectric element 54 and an electrode 156. The hollow portion 45a is converted

with a cap 165 through which plural holes 167 for introducing the air within the tire. These holes 167 are sealed with the sealing board 168 so that the air is not introduced within the hollow portion 45a. The sealing board 45a is made of a high heat-conductivity material. Both electrode 156 and the piezoelectric element 54 are electrically connected wires 157 and 159, respectively. Both wires 157 and 159 inserted in a insulating member 161 and electrically connected to the wire 110. The insulating member 161 is fixed to the housing 45 with a rubber seal member 163. The pressure detecting portion is installed in the rim 3 of the tire in a same manner illustrated in Fig. 1 through Fig.3.

In Fig. 32 and Fig. 33, reference numeral 19 denotes a cylindrical bobbin of ABS resin whose all outer circumference surface is adhered to the inner surface of the rim 3. The first coil 13 of the pressure detecting circuit 270 and the first coil 4 the temperature detecting circuit 280 are separately wound on the outer surface of the bobbin 19. As shown in Fig. 32, a resin case 391 for setting the excitation coil 99 and the receiving coil 101 is installed by a stay 31 inside the bobbin 19 so that the case 391 faces one portion of the bobbin 19, on which the coil 13 is wound, with a gap G1 of 6mm through 10mm. In this installation, the position of the excitation coil 99 is shifted from the position of the receiving coil 101 by 90° for preventing the magnetic coupling between the excitation coil 99 and the receiving coil 101. Independent of the resin case 391, the other resin case 392 for setting the excitation coil 281 and the receiving coil 282 is installed by a stay 31 inside the bobbin 19 so that the case 392 faces the other portion of the bobbin 19, on which the coil 14 is wound, with a gap G2 of 6mm through 10mm as shown in Fig. 33. In this installation, the position of the excitation coil 281 is shifted from the position of the receiving coil 282 by 90° for preventing the magnetic coupling between the excitation coil 281 and the receiving coil 282.

An operation of the third embodiment of the present invention is explained with reference to Fig. 34(a) through Fig. 39. At first, operation characteristics of the pressure detecting circuit 270 and the temperature detecting circuit 280 is explained by using Fig. 34(a) through 35(b). In Fig. 34(a) and Fig. 34(b), when the tire temperature is T1, the corresponding resonant frequency f_T of the temperature detecting 280 becomes f_{T1} at which the phase difference between the excitation voltage and the receiving voltage becomes π/s. Then, the tire temperature becomes T2, the resonant frequency f_T of the temperature detecting circuit 280 is shifted f_{T2}. In Fig. 35(a) and Fig35(b), when the tire pressure is P1, the corresponding resonant frequency f_p of the pressure detecting 270 becomes f_{p1} at which the phase difference between the excitation voltage and the receiving voltage becomes $\pi/2$. Then, when the tire pressure becomes P2, the resonant frequency f_p of the pressure detecting circuit 280 is shifted f_{p2}. Accordingly, the resonant frequencies f_p and f_T are detected by controlling the phase difference between the excitation voltage and the receiving voltage in each circuit so that such phase difference becomes $\pi/2$, as explained in the second embodiment of the present invention.

An operation of the microcomputer 350 is explained below with reference to Fig. 38. In a first step A1, the resonant frequency f_{Tn} is inputted from the temperature detecting circuit 280. Then, the resonant frequency f_{Pn} is inputted from the pressure detecting circuit 270 in a step S3. When the program proceeds to a step S4, a temperature is determined from the first data map shown in Fig. 36 which is stored ROM 103 on the basis of the inputted the resonant frequency f_{Tn}. Then, one characteristic between the tire pressure and the resonant frequency at the tire temperature Tn is specified in the second data map illustrated in Fig. 37 by using the obtained temperature Tn in a step S5. Then, a pressure Pn is determined from the specified characteristic in the second data map in a step S6. In a step S7, the determined tire temperature Tn and the tire pressure Pn are outputted from the microcomputer 350 to the indicator 105. Then, the program returns to the step S2 and repeats the above explained operation in response to the inputted resonant frequency f_{Tn} and f_{pn}.

(Fourth embodiment)

A fourth embodiment of the present invention is explained below with reference to Fig. 39 through Fig. 41(b). According to the fourth embodiment, one frequency changing circuit 33 and one frequency detecting circuit 34 are commonly used in the tire pressure detecting circuit and the temperature detecting circuit as shown in Fig. 39. Namely, both excitation coils 99 and 281 are electrically connected with the frequency changing circuit 33, and both receiving coils 101 and 282 are electrically connected with the frequency detecting circuit 34. In this case, it is necessary that the resonant frequency f_T indicative of the tire temperature is different from the resonant frequency f_p indicative of the tire pressure during the operation because the frequency changing circuit 33 and the frequency detecting circuit 33 and the frequency detecting circuit 34 are used for detecting both resonant frequencies f_T and f_p. For this purpose, the inductance of the first coil 13 is designed so that it differs from that of the first coil 14(or the capacitance of the piezoelectric element 53 is de-

signed so that it differs from that of the piezoelectric element 54). The frequency changing circuit 33 shifts its changing range from one range for the temperature detection to the other range for the pressure detection at a predetermined interval.

In Fig. 40, the first coils 13 and 14 are wounded on the bobbin 19 in a same manner described in the third embodiment. Both the excitation coils 99 and 261 are integrally wound on a iron core 291 which is disposed in a resin case 393. The resin case 393 is installed in the vehicle by the stay 23 so that both the excitation coils 99a and 281 are electromagnetically coupled with the first coils 13 and 14. The gap between the bobbin 19 and the resin case 392 is 6mm through 10mm. Both receiving coils 101 and 282 are installed in the vehicle body in the same manner. However, the position of the receiving coils 101 and 282 are shifted from the position of the excitation coils 99 and 281 by 90° to the wheel shaft for preventing the magnetic coupling between the excitation coils 99 and 281 and the receiving coils 101 and 282.

An operation of the fourth embodiment of the present invention is explained below with reference to Fig. 41(a) and 41(b). In Fig. 41(a) and Fig. 41(b), when the tire temperature is T1, the corresponding resonant frequency f_T of the temperature detecting becomes f_{T1} at which the phase difference between the excitation voltage and the receiving voltage becomes $\pi/2$. Then, when the tire temperature becomes T2, the resonant frequency f_T of the temperature detecting circuit is shifted f_{T2}. In the meantime, when the tire pressure is P1, the corresponding resonant frequency f_p of the pressure detecting becomes f_{p1} at which the phase difference between the excitation voltage and the receiving voltage becomes $\pi/2$. Then, when the tire pressure becomes P2, the resonant frequency f_p of the pressure detecting circuit is shifted f_{p2}. Accordingly, the resonant frequencies $f_{pY \text{ and } fT}$ are detected by controlling the phase difference between the excitation voltage and the receiving voltage in each circuit so that such phase difference becomes $\pi/2$, as explained in the second embodiment of the present invention. Thereafter, the tire temperature and the tire pressure are computed by the microcomputer 350 as explained in the above third embodiment.

(Fifth embodiment)

A fifth embodiment of the present invention is explained below with reference to Fig. 42 through Fig. 48. According to the fifth embodiment, the piezoelectric elements 53 and 54 are horizontally disposed in the tire as shown in Fig. 42 for the purpose of increasing the detecting area thereof. Namely, the pressure detecting portion 209 is fixed to the rim 3 so that the cap 65, the piezoelectric elements 53 and 54 and the cap 650 are substantially parallel to the rim 3.

The detail structure of the pressure detecting portion 209 is explained below. In Fig. 42, reference numeral 68 designates a metal filter which is made of sintered porus metal and disposed within the pressure introducing holes 67 for preventing the sudden pressure change from being transferred to the diaphragm 47. The end portion of the diaphragm 49 is sandwiched with rubber sheets 481 and soft metal sheets 482 between the cap 65 and the step portion 47 as shown in Fig. 43 in order to seal the low pressure chamber 69. Other structure of the pressure detecting portion 209 is the same as that of the pressure detecting portion 109 of the third embodiment illustrated in Fig. 31 except the cap 650. The cap 650 has a bolt portion 651 which is integrally formed therewith. A screw portion 166 is formed on the end of the bolt portion 651. The bolt portion 651 is inserted a through hole 3a of the rim 3 and a through hole 19a of the bobbin 19. Then, the screw portion 166 is coupled with a nut 74. According to this coupling structure, the pressure detecting portion 209 is fixed to the rim together with the bobbin 19. Further, the bobbin 19 is firmly fixed by driving few pins 20 between the rim 3 and the bobbin 19 as shown in Fig. 47. In this case, the inside of the tire is sealed with an o ring 19 which is provided in a circular groove 650a of the cap 650. In Fig. 45 and Fig. 46, reference numeral 10a designates connecting pins which is electrically connected through a connecting line 10 and 11 with the piezoelectric element 53, and reference numeral 12a designates connecting pins which is electrically connected through a connecting line 12 with the piezoelectric element 54. The connecting lines 10 and 12 are provided through the cap 650 and the bolt portion 651. In Fig. 46, reference numeral 164 denotes pin insulating member. In Fig. 44, reference numerals 10b and 12b designate connecting holes in which the connecting pins 10a and 12a are respectively inserted so that the connecting pins 10a and 12a are electrically connected with the connecting holes 10b and 12b, respectively. The connecting holes 10b and 12b are electrically connected with the first coils 13 and 14, respectively.

According to the fifth embodiment, the piezoelectric elements 53 and 54 have an influence of centrifugal force because the piezoelectric elements 53 and 54 are horizontally disposed in the tire as shown in Fig. 42. So, for the purpose of compensating such an effect, as shown in Fig. 48, the CPU 104 of the microcomputer 350 computes the centrifugal force based on the wheel rotation speed signal from a wheel rotation speed sensor 106, and then compensates the obtained tire pres-

sure which is computed in accordance with the change of the capacity of the piezoelectric elements 53.

(Sixth embodiment)

A sixth embodiment of the present invention is explained below with reference to Fig. 49 through Fig. 51 According to the sixth embodiment, the frequency changing circuit 33 includes a first frequency changing circuit 334, which changes the frequency for detecting the tire pressure, and a second frequency changing circuit 335 which changes the frequency for detecting the tire temperature. The first frequency changing circuit 334 outputs the alternating voltage whose waveform is shown in Fig. 50(a). The frequency changing circuit 335 outputs the alternating voltage whose waveform is shown in Fig. 50(b). Both frequency changing circuits 334 and 335 are electrically connected with synthesizing circuit 333 in which the excitation voltage shown in Fig. 50(c) is synthesized based on the alternating voltage outputted from the frequency changing circuits 334 and 335. The synthesized excitation voltage is applied to the excitation coils 99 and 281. On the other hand, the frequency detecting circuit 34 includes a separating circuit 343 which separates a receiving voltage shown in Fig. 51(a) into the two different voltage having the different frequency. One separated voltage shown in Fig. 50(b) is inputted in a first frequency detecting circuit 344. The other separated voltage shown in Fig. 50(c) is inputted in a first frequency detecting circuit 345. The first frequency detecting circuit 344 detects the resonant frequency indicative of the tire pressure when the phase difference between the alternating voltage shown in Fig. 50(a) and the separated voltage shown in Fig. 51(b) becomes $\pi/2$. The second frequency detecting circuit 345 detects the resonant frequency indicative of the tire temperature when the phase difference between the alternating voltage shown in Fig. 50(b) and the separated voltage shown in Fig. 51(c) becomes $\pi/2$. The detected resonant frequencies are inputted in the microcomputer 350 which determines the corresponding tire pressure and tire temperature based on the detected resonant frequencies. The detected tire pressure and the tire temperature are indicated by the indicator as described in the fourth and fifth embodiments.

(Seventh embodiment)

A seventh embodiment of the present invention is explained below with reference t Fig. 52 and Rig. 53. This embodiment relates to an other example of the pressure detecting portion 309. In Fig. 52, cylindrical diaphragm 490 are fixed to the inner wall of the housing 45 by welding. For the purpose of preventing the excess deviation of the diaphragm 490, a stopper 50 is disposed within the low pressure chamber 69. Therefore, even when the tire pressure increases suddenly or when the tire pressure exceeds the standard value, the deviation of the diaphragm 490 is stopped by the stopper as shown in Fig. 53 so that its excess deviation is prevented. Other elements and structure of the pressure detecting portion 309 are the same as those shown in Fig. 42.

Although only a few embodiments have been described in detail above, those having ordinary skill in the art will certainly understand that many modifications are possible in the preferred embodiment without departing from the teachings thereof.

All such modifications are intended to be encompassed within the following claims.

Claims

1. A tire pressure detecting apparatus for detecting a tire pressure of a vehicle, comprising:

   pressure-capacity transforming means, provided within said tire, for transforming the tire pressure change into electrostatic capacity change;

   resonant signal producing means, electrically connected with said pressure-capacity transforming means within said tire, for producing a resonant electric signal having a resonant frequency in accordance with the capacity change generated from said pressure-capacity transforming means;

   voltage supplying means, provided in said vehicle, for supplying said resonant signal producing means with alternating voltage whose frequency is changed within a predetermined range including said resonant frequency;

   resonant signal receiving means, provided in said vehicle, for receiving said resonant electric signal produced from said resonant signal producing means; and

   pressure detecting means, provided in said vehicle, for detecting the tire pressure based on said received resonant electric signal.

2. A tire pressure detecting apparatus according to claim 1, wherein said pressure-capacity transforming means includes a piezoelectric element.

3. A tire pressure detecting apparatus according to claim 1,. wherein said pressure-capacity transforming means includes a housing which is provided within said tire;

   a first chamber provided within said housing so that the pressure of said first chamber is maintained at a predetermined value;

a second chamber provided within said housing for introducing the tire pressure into said second chamber; and

a piezoelectric element provided within said housing so as to be deformed by the pressure difference between the predetermined pressure of said first chamber and the tire pressure of said second pressure, whereby the capacity of said piezoelectric element is changed in accordance with its deformation.

4. A tire pressure detecting apparatus according to claim 1, wherein said pressure-capacity transforming means includes a housing which is provided within said tire;

a first chamber provided within said housing so that the pressure of said first chamber is maintained at a predetermined value;

a second chamber provided within said housing for introducing the tire pressure into said second chamber;

a diaphragm provided between said first chamber and second chamber so as to be deformed by the pressure difference between the predetermined pressure of said first chamber and the tire pressure of said second pressure; and

a piezoelectric element provided on said diaphragm so as to be deformed by said deformation of said diaphragm, whereby the capacity of said piezoelectric element is changed in accordance with its deformation.

5. A tire pressure detecting apparatus according to claim 1, wherein said resonant signal producing means is electromagnetically coupled with said voltage supplying means and resonant signal receiving means.

6. A tire pressure detecting apparatus according to claim 1, wherein said pressure detecting means includes resonant frequency determining moans for determining that said received resonant electric signal has said resonant frequency;

tire pressure determining means for determining the corresponding tire pressure by using the determination result of said resonant frequency determining means and a data map showing the relationship between said resonant frequency and said tire pressure.

7. A tire pressure detecting apparatus according to claim 6, wherein said resonant frequency determining means determines that said received resonant electric signal has said resonant frequency when the electric current of said received resonant electric signal becomes minimal.

8. A tire pressure detecting apparatus according to claim 6, wherein said resonant frequency determining means determines that said received resonant electric signal has said resonant frequency when a phase difference between said alternating voltage and said received resonant electric signal becomes $\pi/2$.

9. A tire pressure detecting apparatus for detecting a tire pressure of a vehicle, comprising:

a housing provided within said tire;

a first chamber provided within said housing so that the pressure of said first chamber is maintained at a predetermined value;

a second chamber, provided within said housing, for introducing the tire pressure into said second chamber;

a piezoelectric element provided within said housing so as to be deformed by a pressure difference between the predetermined pressure of said first chamber and the tire pressure of said second pressure, whereby the capacity of said piezoelectric element is changed in accordance with its deformation;

a first coil electrically connected with said capacity changing means within said tire;

a excitation coil, provided in the vehicle, which is electromagnetically coupled with said first coil for exciting said first coil;

excitation voltage supplying means for supplying said excitation coil with an excitation voltage whose frequency is changed within a predetermined range including a resonant frequency;

a receiving coil, provided in the vehicle, which is electromagnetically coupled with said first coil for receiving induced voltage from said first coil;

resonant frequency determining means for determining that said induced voltage has said resonant frequency; and

tire pressure determining means for determining the corresponding tire pressure by using the determination result of said resonant frequency determining means and a data map showing the relationship between said resonant frequency and said tire pressure.

10. A tire pressure detecting apparatus according to claim 9, wherein said resonant frequency determining means determines that said induced voltage has said resonant frequency when electric current, generated by said induced voltage, becomes minimal.

11. A tire pressure detecting apparatus according

to claim 9, wherein said resonant frequency determining means determines that said induced voltage has said resonant frequency when a phase difference between said alternating voltage and said induced voltage becomes $\pi/2$.

12. A tire pressure detecting apparatus for detecting a tire pressure of a vehicle, comprising:

first pressure-capacity transforming means, provided within said tire, for transforming the tire pressure change into electrostatic capacity change;

second pressure-capacity transforming means, provided within said tire, for transforming the tire pressure temperature into electrostatic capacity change;

first resonant signal producing means, electrically connected with said first pressure-capacity transforming means within said tire, for producing a first resonant electric signal having a first resonant frequency in accordance with the capacity change generated from said first pressure-capacity transforming means;

second resonant signal producing means, electrically connected with said second pressure-capacity transforming means within said tire, for producing a second resonant electric signal having a second resonant frequency on in accordance with the capacity change generated from said second pressure-capacity transforming means;

first voltage supplying means, provided in said vehicle, for supplying said first resonant signal producing means with alternating voltage having at least said first resonant frequency;

second voltage supplying means, provided in said vehicle, for supplying said second resonant signal producing means with alternating voltage having at least said second resonant frequency;

first resonant signal receiving means, provided in said vehicle, for receiving said first resonant electric signal produced from said first resonant signal producing means;

second resonant signal receiving means, provided in said vehicle, for receiving said second resonant electric signal produced from said second resonant signal producing means;

pressure detecting means, provided in said vehicle, for detecting the tire pressure based on said first received resonant electric signal; and

temperature detecting means, provided in said vehicle, for detecting the tire temperature based on said second received resonant electric signal.

13. A tire pressure detecting apparatus according to claim 12, wherein said first pressure-capacity transforming means includes a piezoelectric element.

14. A tire pressure detecting apparatus according to claim 12, wherein said second pressure-capacity transforming means includes a piezoelectric element.

15. A tire pressure detecting apparatus according to claim 12, wherein said first resonant signal producing means is electromagnetically coupled with said first voltage supplying means and first resonant signal receiving means.

16. A tire pressure detecting apparatus according to claim 12, wherein said second resonant signal producing means is electromagnetically coupled with said second voltage supplying means and first resonant signal receiving means.

17. A tire pressure detecting apparatus according to claim 12, wherein said pressure detecting means includes resonant frequency determining means for determining that said first received resonant electric signal has said first resonant frequency;

tire pressure determining means for determining the corresponding tire pressure by using the determination result of said first resonant frequency determining means and a data map showing the relationship between said first resonant frequency and said tire pressure.

18. A tire pressure detecting apparatus according to claim 12, wherein said temperature detecting means includes resonant frequency determining means for determining that said second received resonant electric signal has second first resonant frequency;

tire temperature determining means for determining the corresponding tire temperature by using the determination result of said second resonant frequency determining means and a data map showing the relationship between said resonant frequency and said tire pressure.

19. A tire pressure detecting apparatus according to claim 12, further comprises indication means for separately indicating said detected tire pressure and said detected tire temperature.

20. A tire pressure detecting apparatus for detecting a tire pressure of a vehicle, comprising:

first pressure-capacity transforming means, provided within said tire, for transforming the tire pressure change into electrostatic capacity change;

second pressure-capacity transforming means, provided within said tire, for transforming the tire pressure temperature into electrostatic capacity change;

first resonant signal producing means, electrically connected with said first pressure-capacity transforming means within said tire, for producing a first resonant electric signal having a first resonant frequency in accordance with the capacity change generated from said first pressure-capacity transforming means;

second resonant signal producing means, electrically connected with said second pressure-capacity transforming means within said tire, for producing a second resonant electric signal having a second resonant frequency in accordance with the capacity change generated from said second pressure-capacity transforming means;

voltage supplying means, provided in said vehicle, for supplying said first and resonant signal producing means with alternating voltage having at least said first and second resonant frequencies;

first resonant signal receiving means, provided in said vehicle, for receiving said first resonant electric signal produced from said first resonant signal producing means;

second resonant signal receiving means, provided in said vehicle, for receiving said second resonant electric signal produced from said second resonant signal producing means;

pressure detecting means, provided in said vehicle, for detecting the tire pressure based on said first received resonant electric signal; and

temperature detecting means, provided in said vehicle, for detecting the tire temperature based on said second received resonant electric signal.

21. A tire pressure detecting apparatus according to claim 20, wherein said first and second pressure-capacity transforming means include a piezoelectric element.

22. A tire pressure detecting apparatus according to claim 20, wherein said first resonant signal producing means is electromagnetically coupled with said voltage supplying means and first resonant signal receiving means.

23. A tire pressure detecting apparatus according to claim 20, wherein said second resonant signal producing means is electromagnetically coupled with said voltage supplying means and first resonant signal receiving means.

24. A tire pressure detecting apparatus according to claim 20, wherein said pressure detecting means includes resonant frequency determining means for determining that said first received resonant electric signal has said first resonant frequency;

tire pressure determining means for determining the corresponding tire pressure by using the determination result of said first resonant frequency determination means and a data map showing the relationship between said first resonant frequency and said tire pressure.

25. A tire pressure detecting apparatus according to claim 20, wherein said temperature detecting means includes resonant frequency determining means for determining that said second received resonant electric signal has second first resonant frequency;

tire temperature determining means for determining the corresponding tire temperature by using the determination result of said second resonant frequency determining means and a data map showing the relationship between said second resonant frequency and said tire pressure.

26. A tire pressure detecting apparatus according to claim 20, further comprises indication means for separately indicating said detected tire pressure and said detected tire temperature.

FIG.1

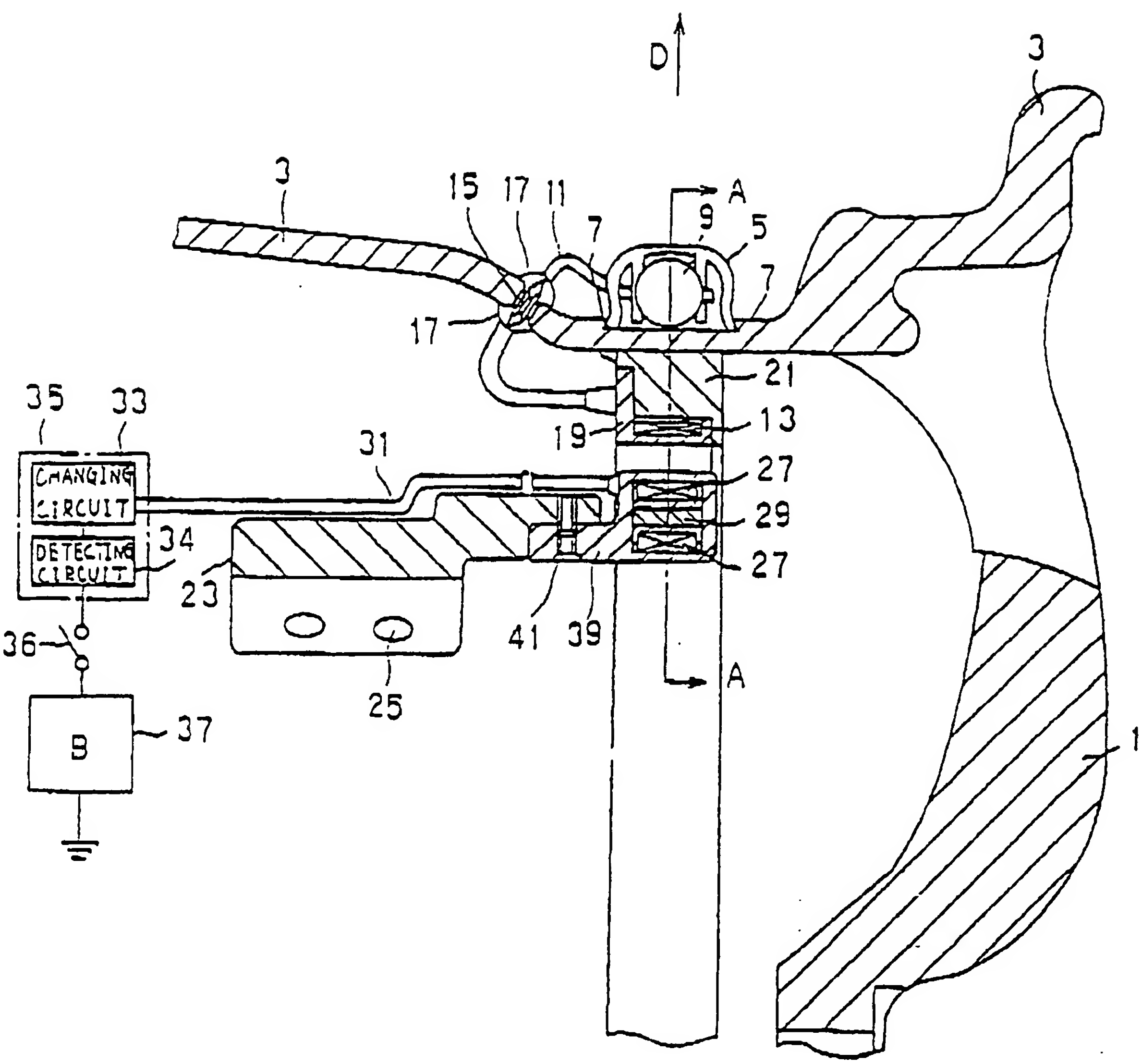

D
A
A
3
3
15
17
11
7
9
5
7
17
21
35
33
31
19
13
27
29
27
CHANGING CIRCUIT
DETECTING CIRCUIT
34
23
41
39
36
25
B
37
1

FIG.2

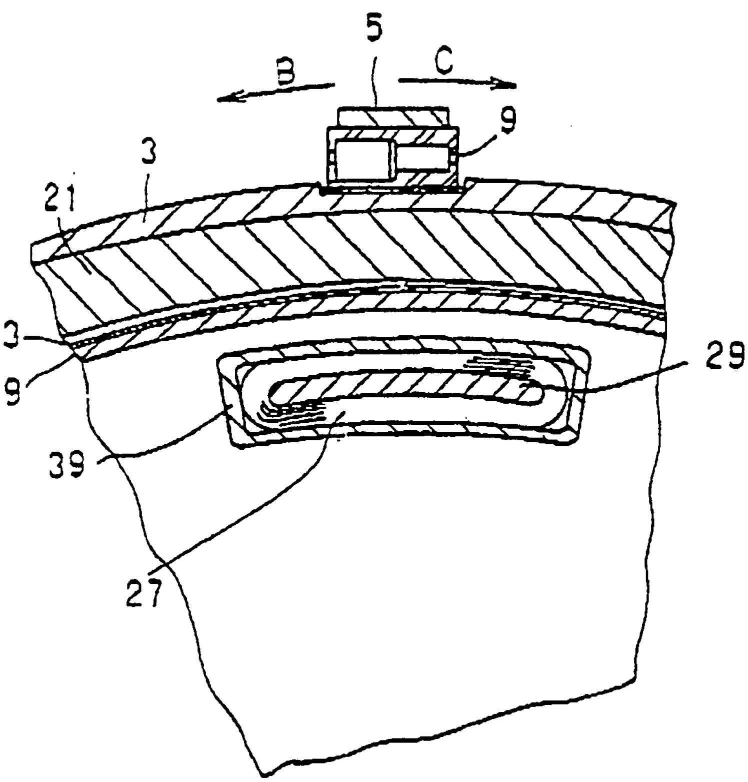


FIG.3

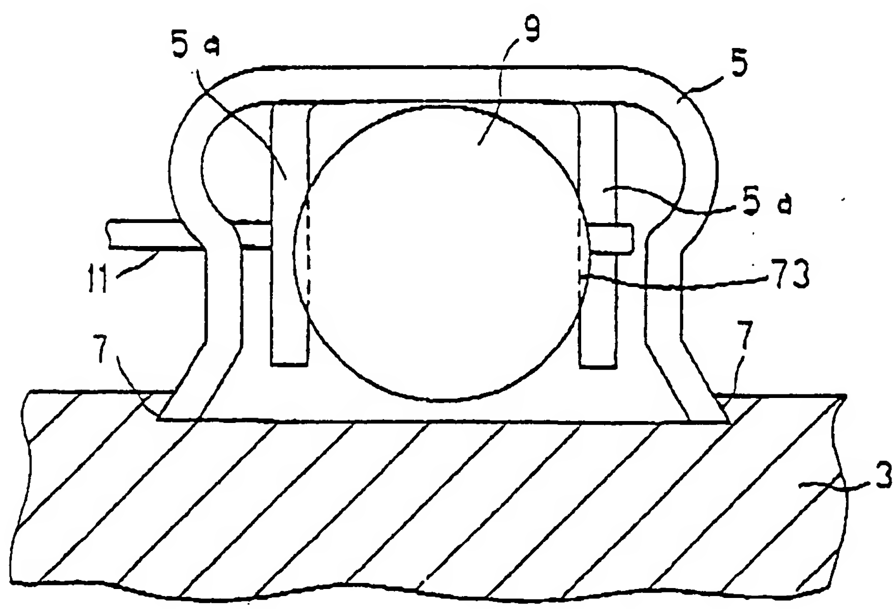


FIG.4

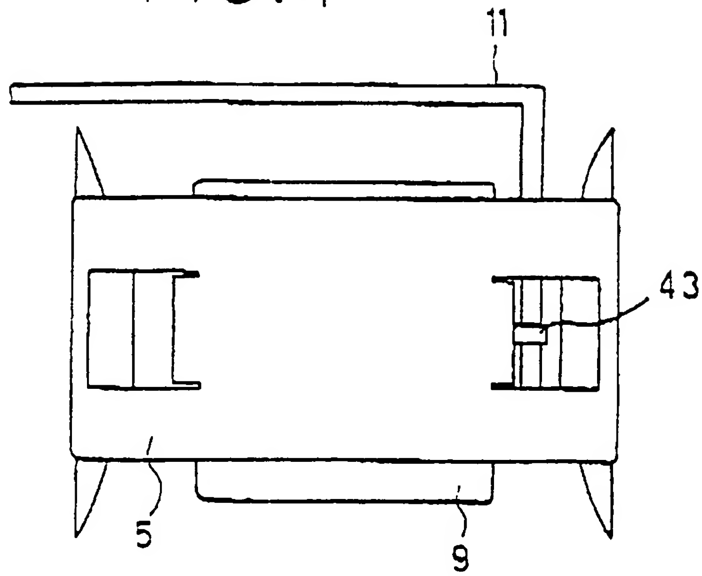

11
43
5
9

FIG.5

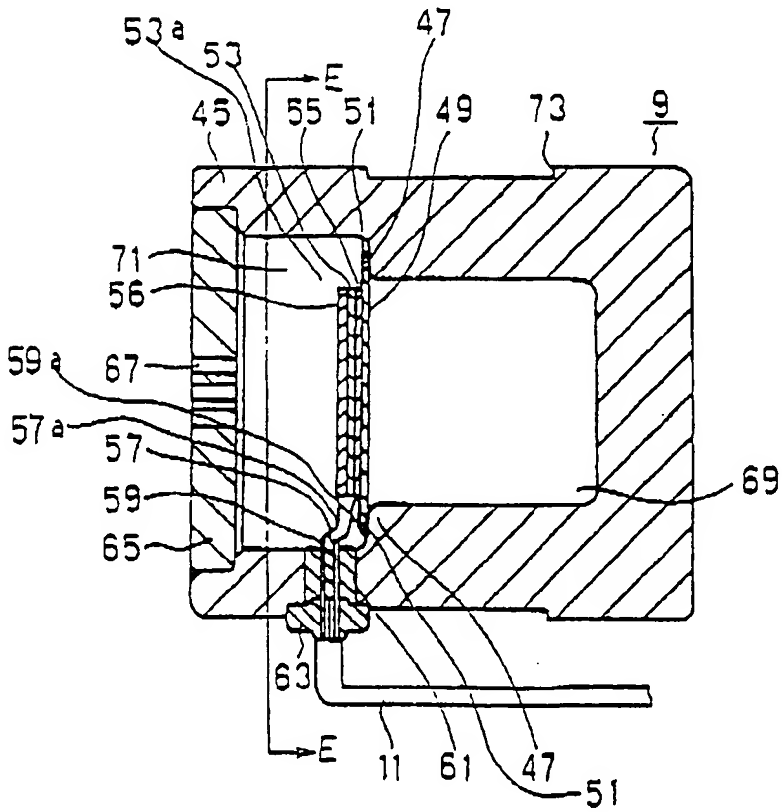

53a
53
47
E
45
55
51
49
73
9
71
56
59a
67
57a
57
59
65
69
63
E
11
61
47
51

FIG.6

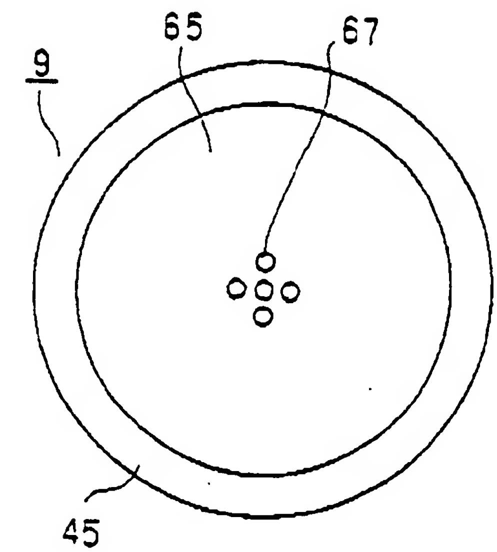


FIG.7

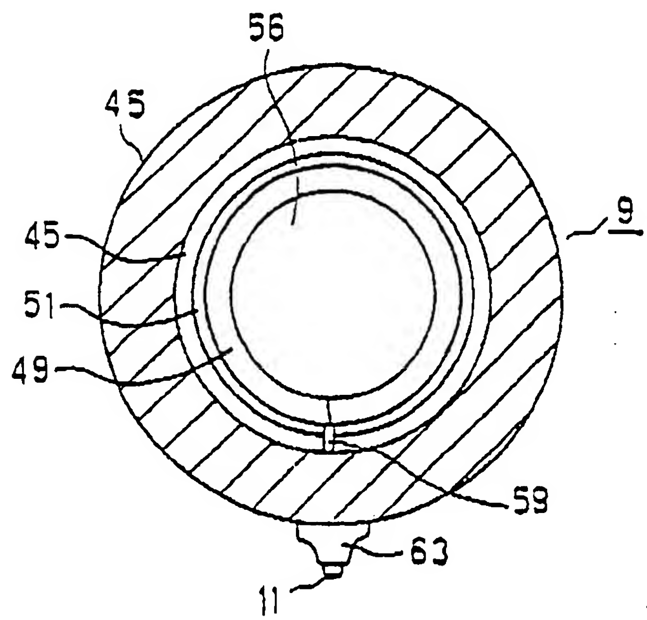


FIG.8

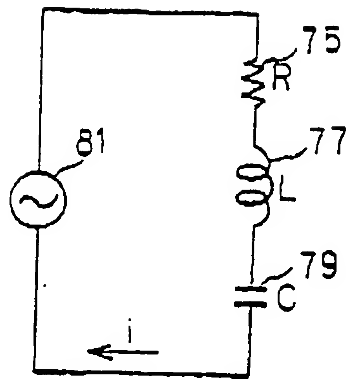


FIG.9

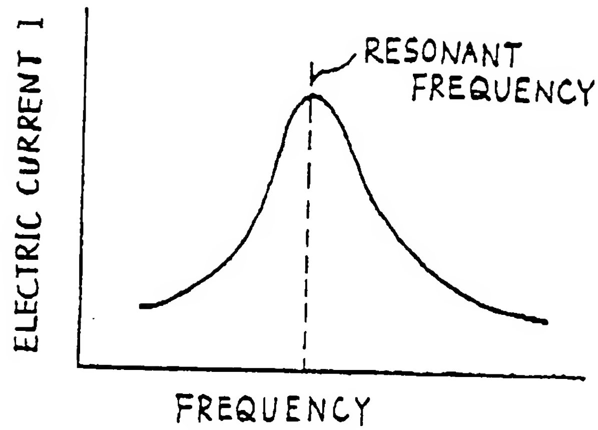


FIG.10

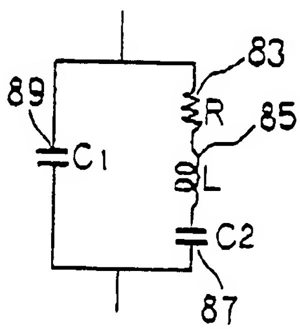


FIG.11

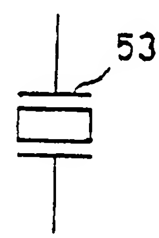


FIG.12

FIG.13

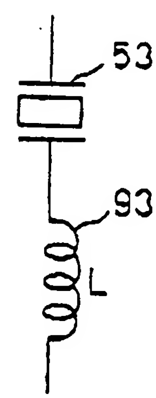


FIG.14

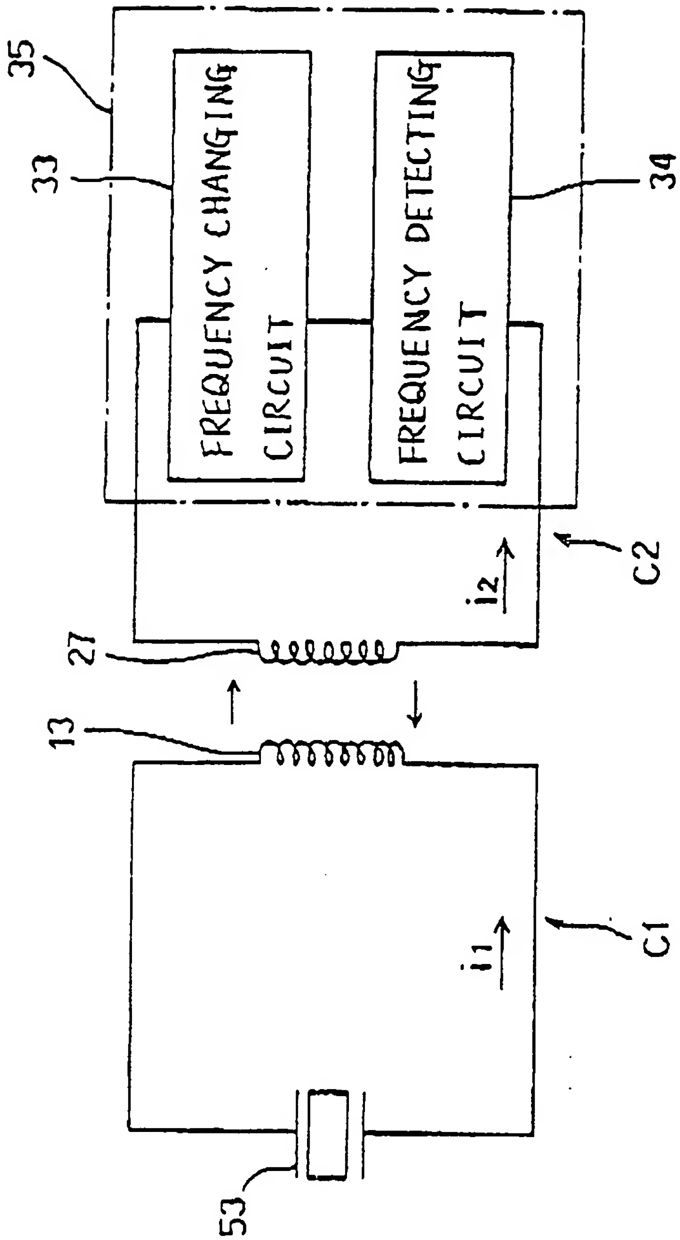

35
33
FREQUENCY CHANGING CIRCUIT
FREQUENCY DETECTING CIRCUIT
34
C2
i2
27
13
i1
C1
53

FIG.15

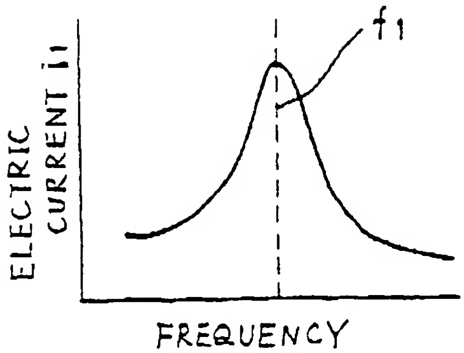

f1
ELECTRIC CURRENT i1
FREQUENCY

FIG.16

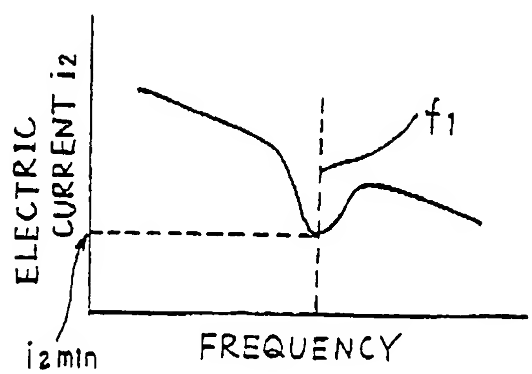

f1
ELECTRIC CURRENT i2
i2min
FREQUENCY

FIG.17

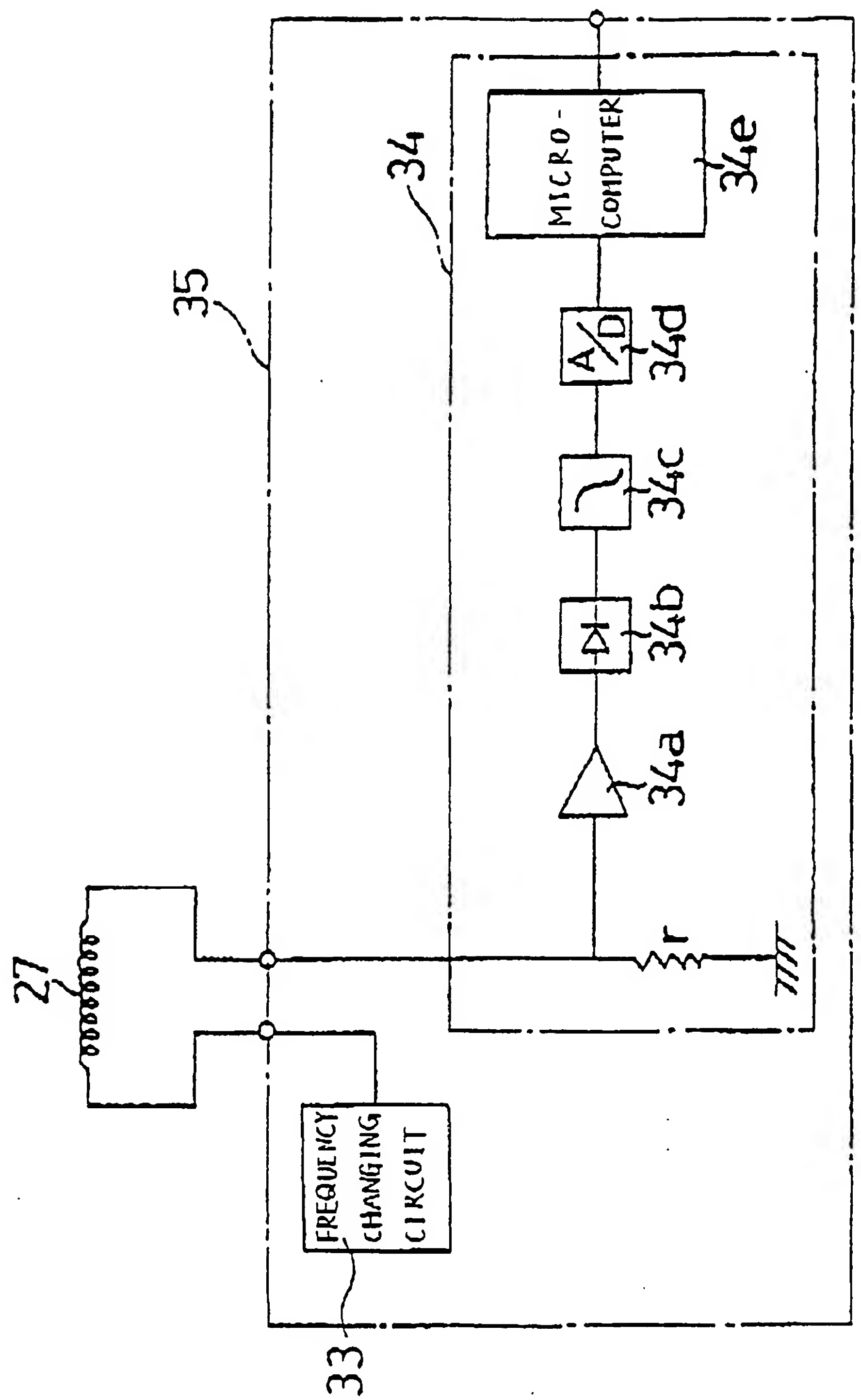

27
35
34
MICRO-COMPUTER
34e
A/D
34d
34c
34D
34a
r
FREQUENCY CHANGING CIRCUIT
33

FIG.18

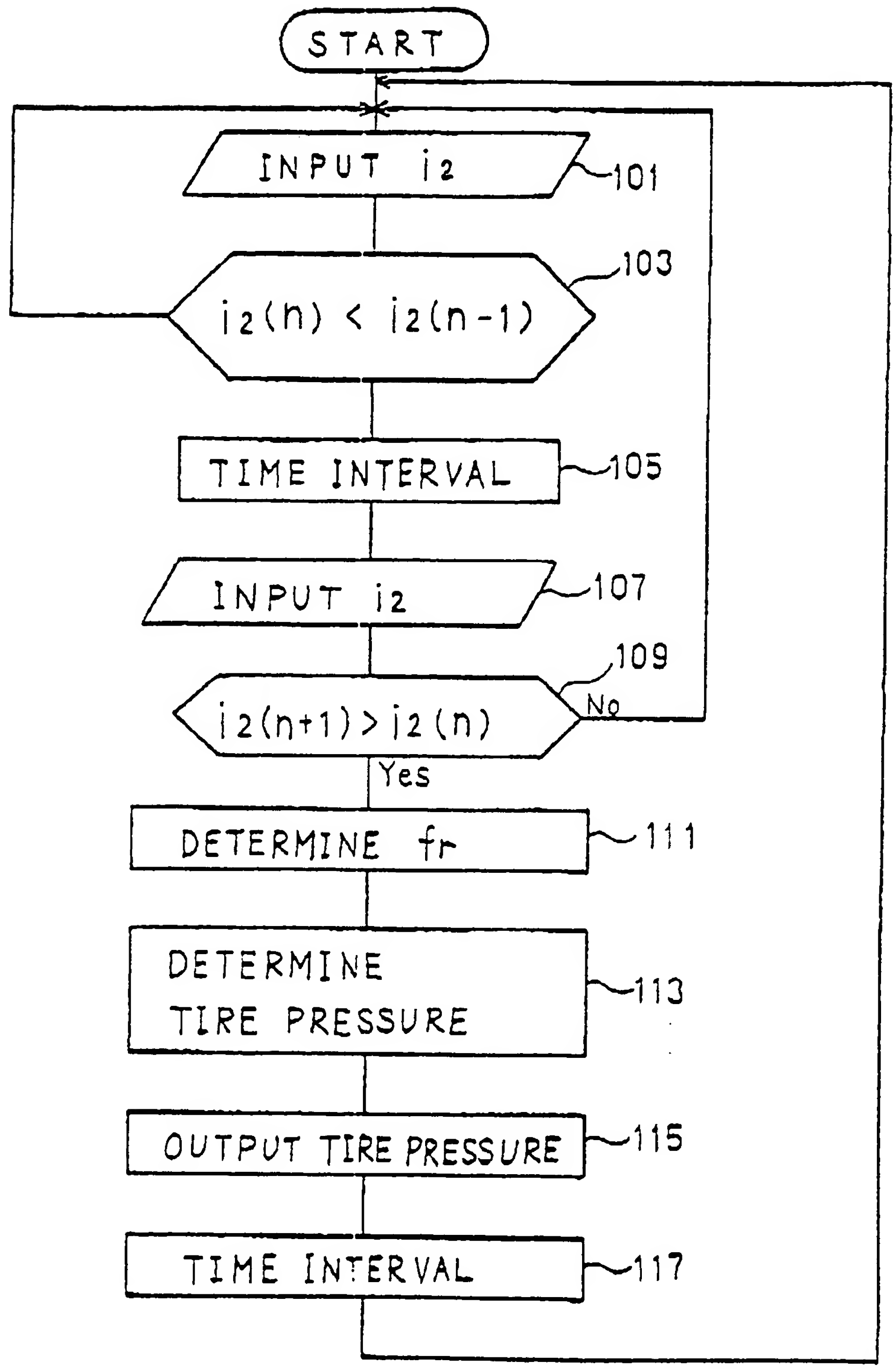

START
INPUT i_2
101
$i_2(n) < i_2(n-1)$
103
TIME INTERVAL
105
INPUT i_2
107
109
$i_2(n+1) > i_2(n)$
No
Yes
DETERMINE fr
111
DETERMINE
TIRE PRESSURE
113
OUTPUT TIRE PRESSURE
115
TIME INTERVAL
117

FIG.19

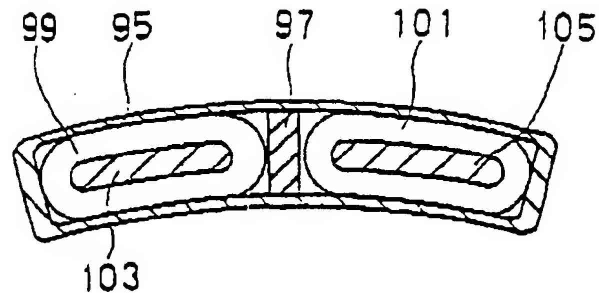


FIG.22

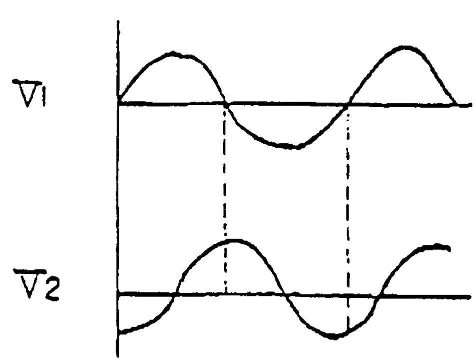


FIG.20

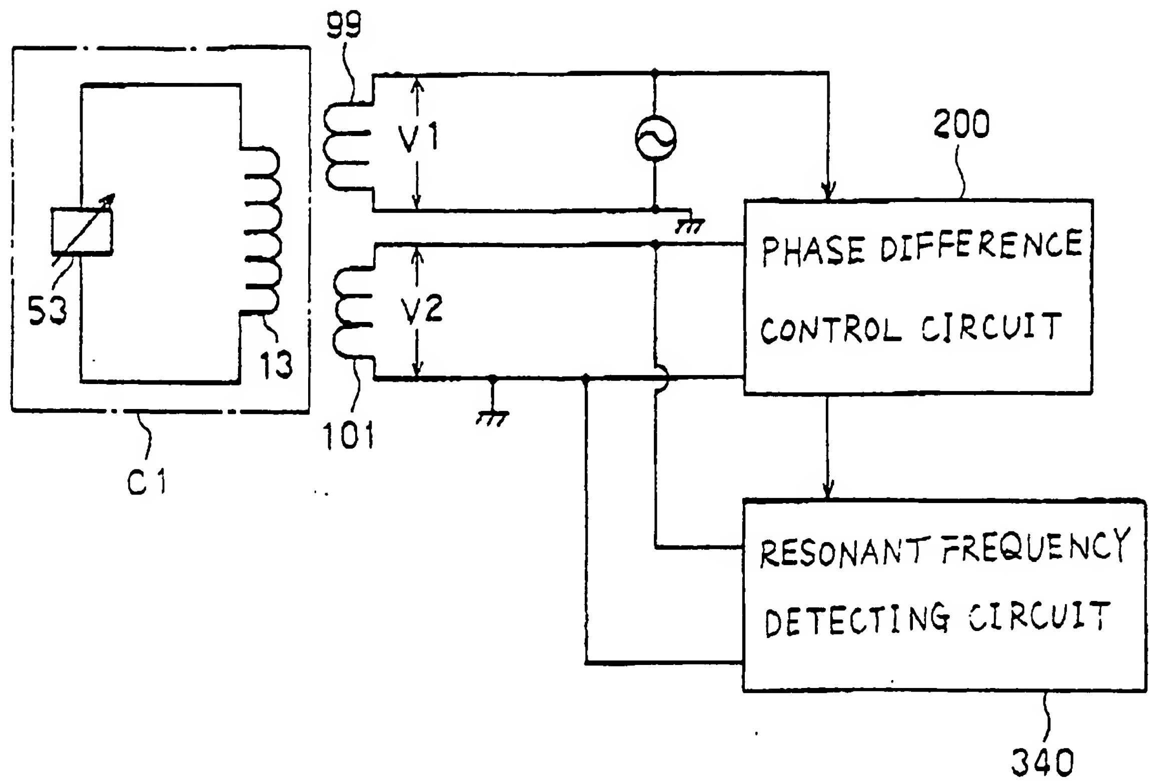

99
V1
200
PHASE DIFFERENCE
CONTROL CIRCUIT
53
V2
13
101
C1
RESONANT FREQUENCY
DETECTING CIRCUIT
340

FIG.21

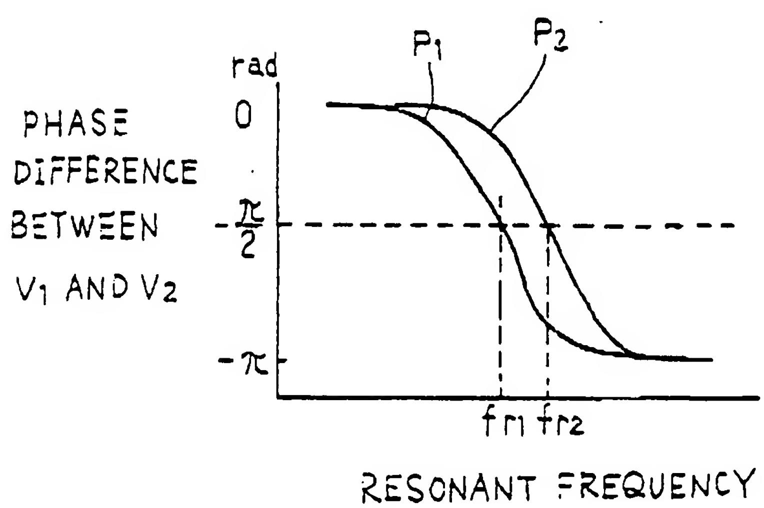

P1
P2
rad
0
PHASE
DIFFERENCE
BETWEEN
V1 AND V2
-π/2
-π
fr1 fr2
RESONANT FREQUENCY

FIG. 23

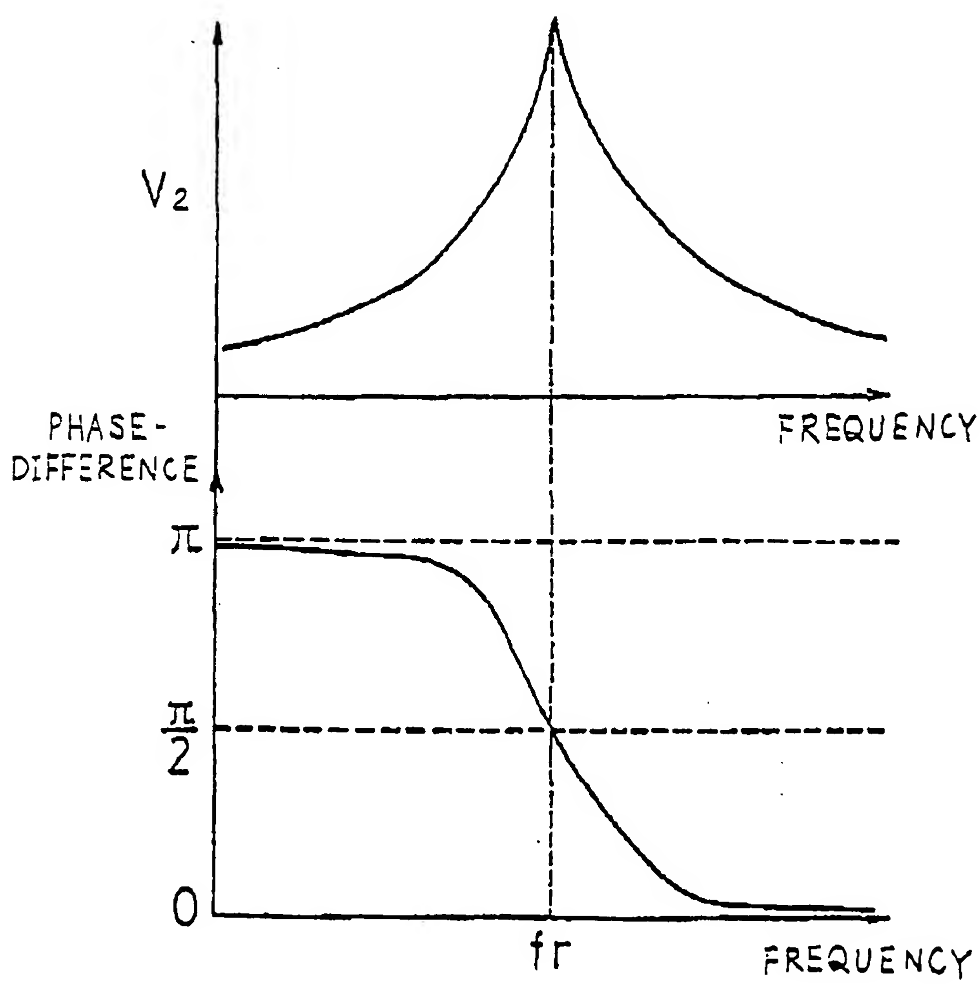


FIG.24

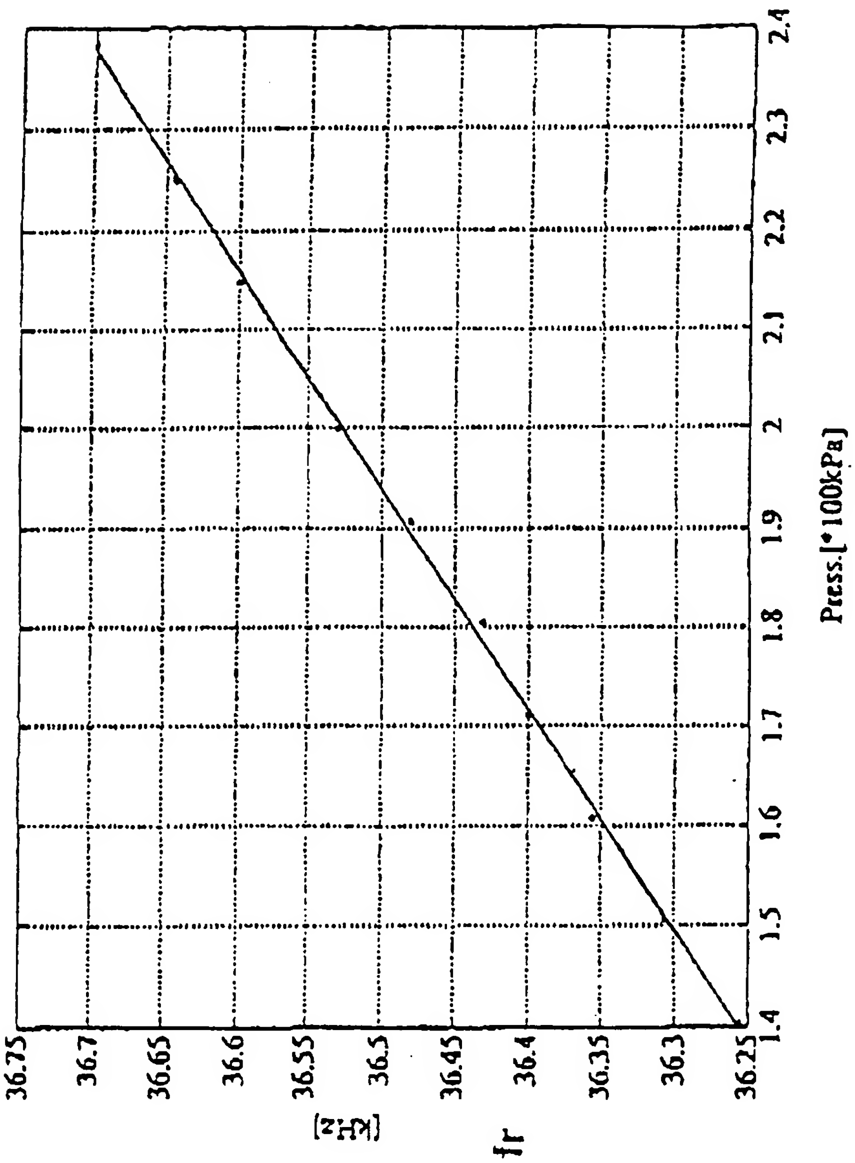

fr
[KHz]
36.75
36.7
36.65
36.6
36.55
36.5
36.45
36.4
36.35
36.3
36.25
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
Press.[*100kPa]

FIG.25

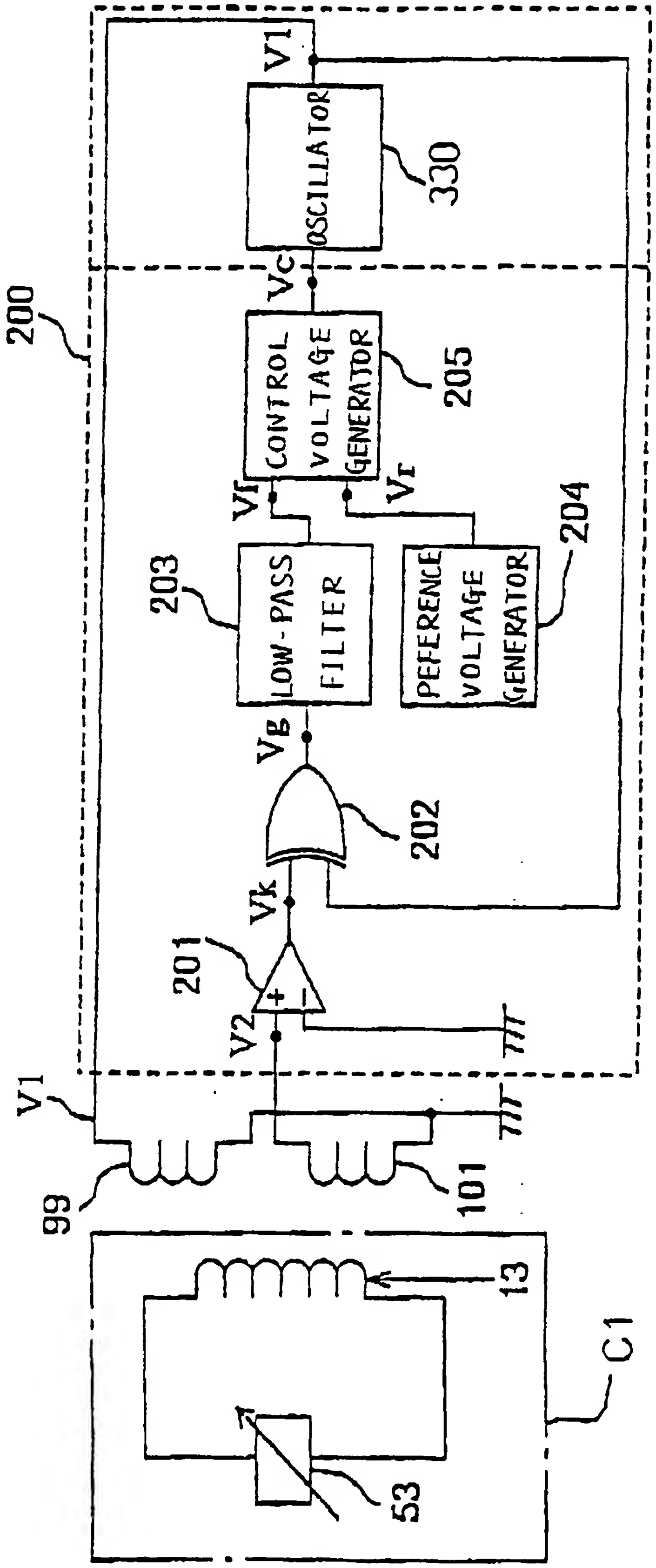

V1
OSCILLATOR
330
Vc
CONTROL VOLTAGE GENERATOR
205
200
Vf
Vr
204
LOW-PASS FILTER
203
PEFERENCE VOLTAGE GENERATOR
VB
202
Vk
201
V2
V1
99
101
13
C1
53

FIG. 26

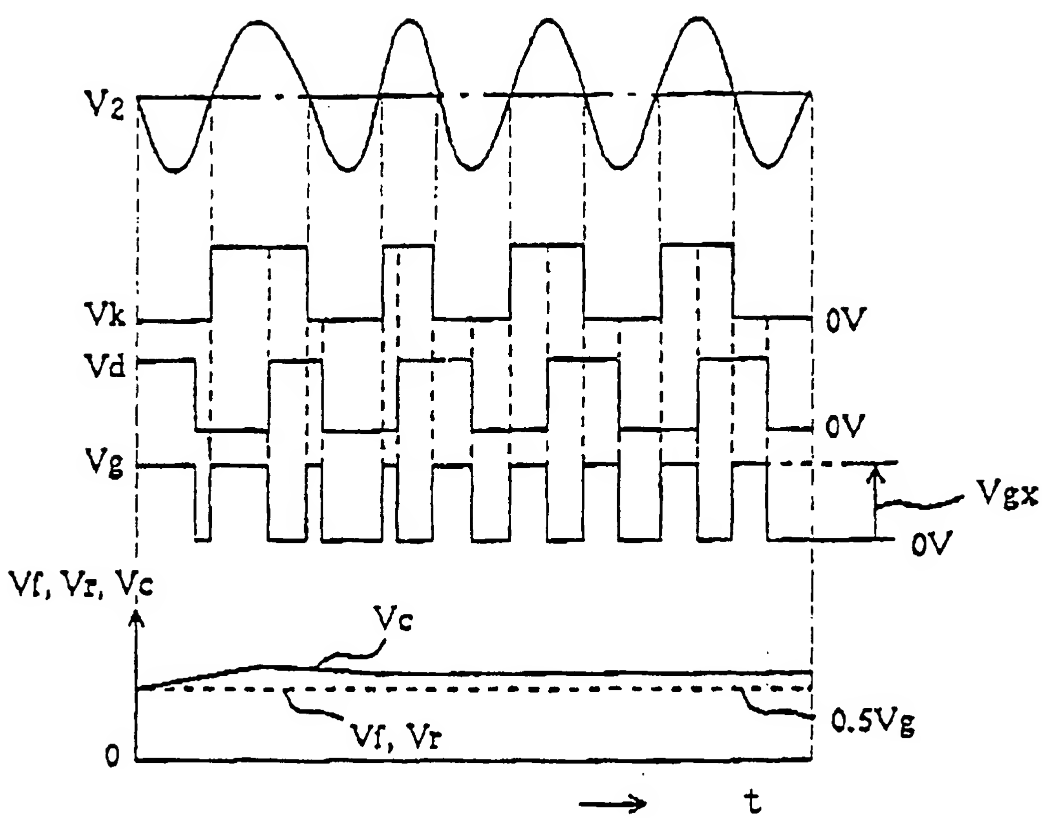


FIG.27

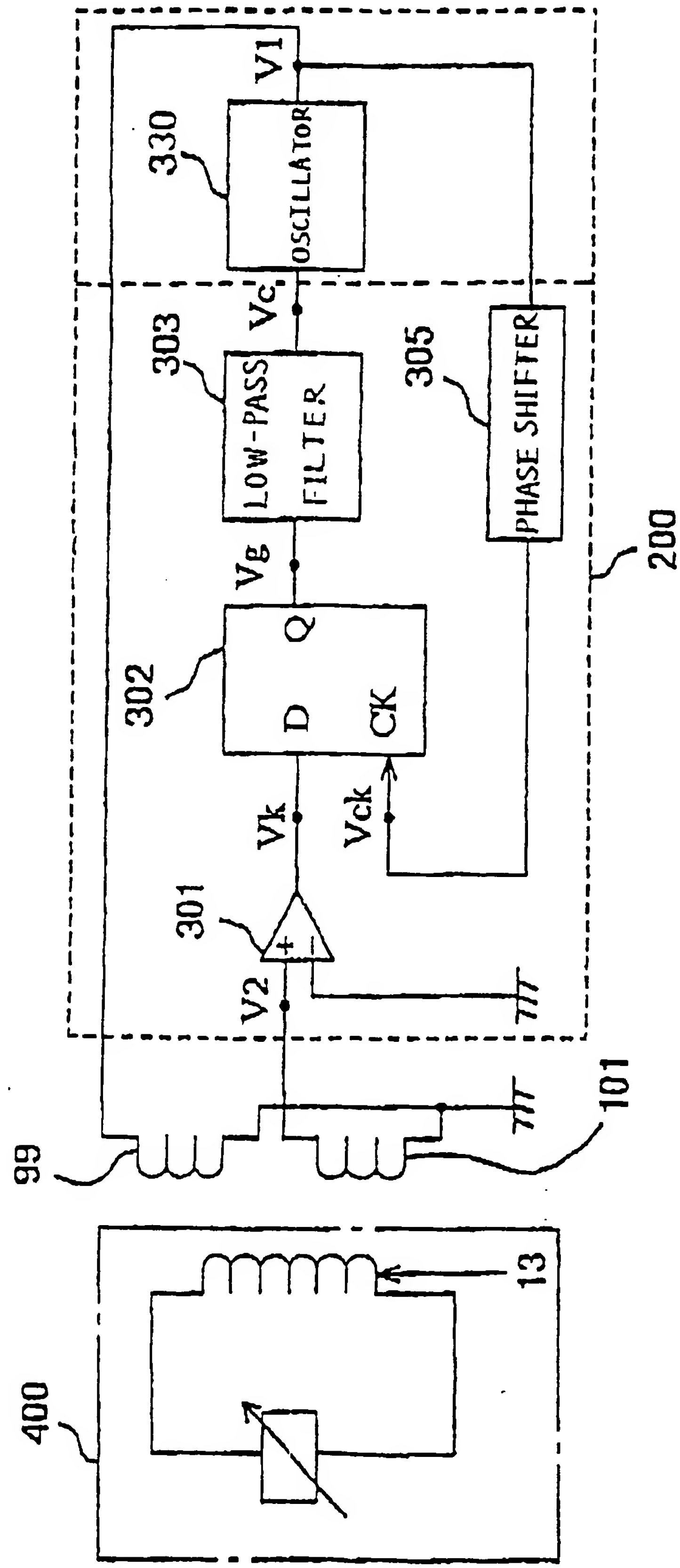

330
OSCILLATOR
V1
Vc
303
LOW-PASS
FILTER
305
PHASE SHIFTER
200
Vg
302
D
Q
CK
Vk
Vck
301
+
-
V2
99
101
13
400

FIG.28

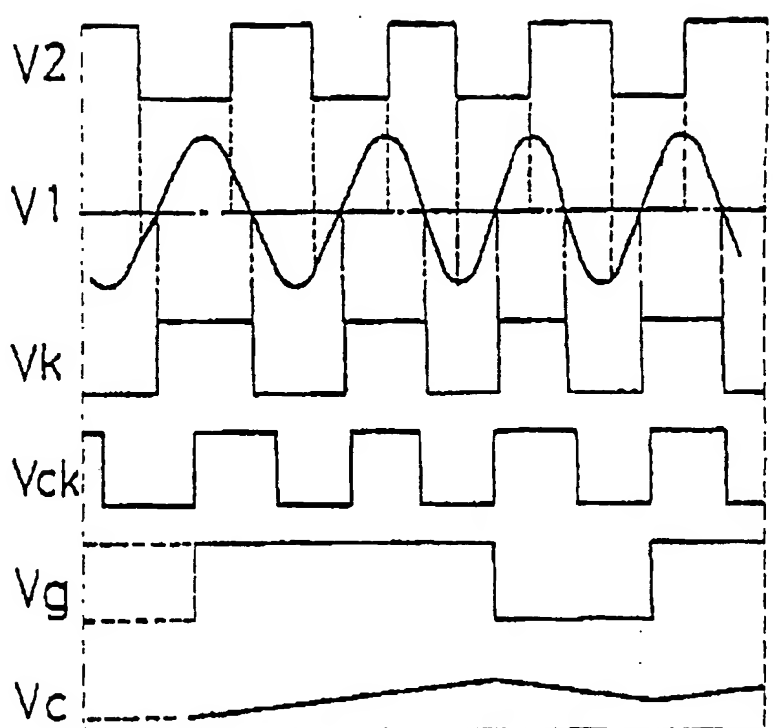


FIG.29

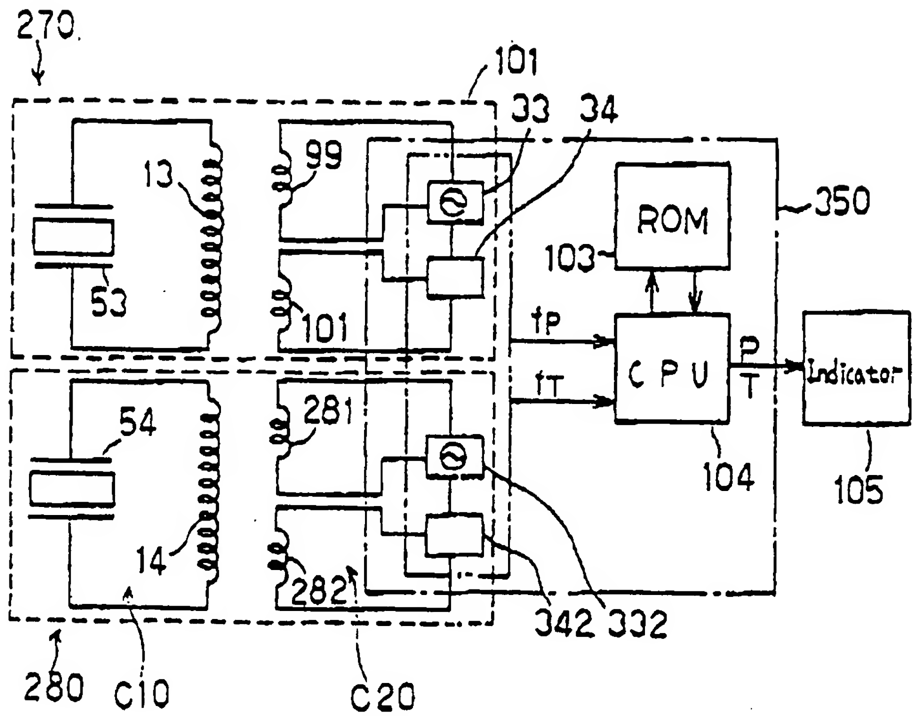

270
101
33
34
99
13
350
ROM
103
53
101
fP
fT
C P U
P
T
Indicator
54
281
104
105
14
282
342
332
280
C10
C20

FIG. 30

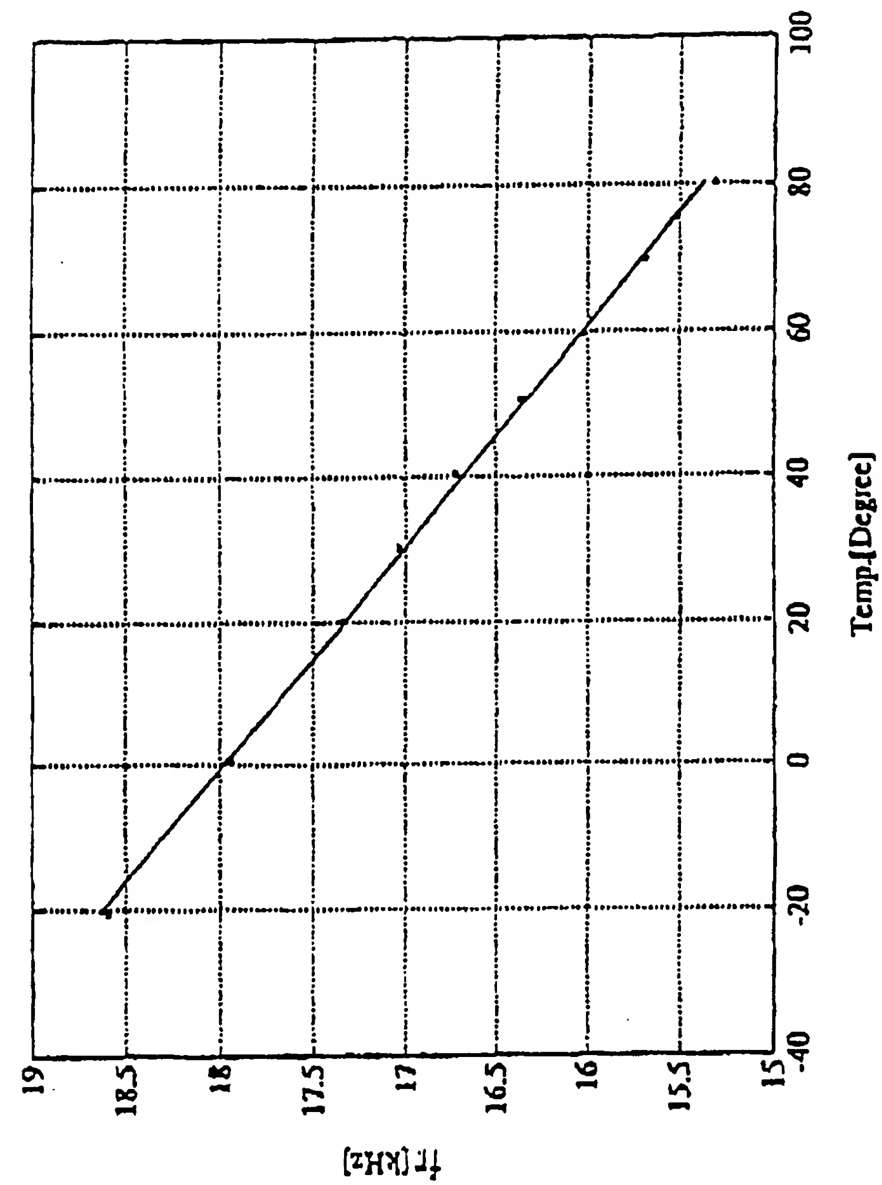

19
18.5
18
17.5
17
16.5
16
15.5
15
fr[kHz]
-40
-20
0
20
40
60
80
100
Temp.[Degree]

FIG.31

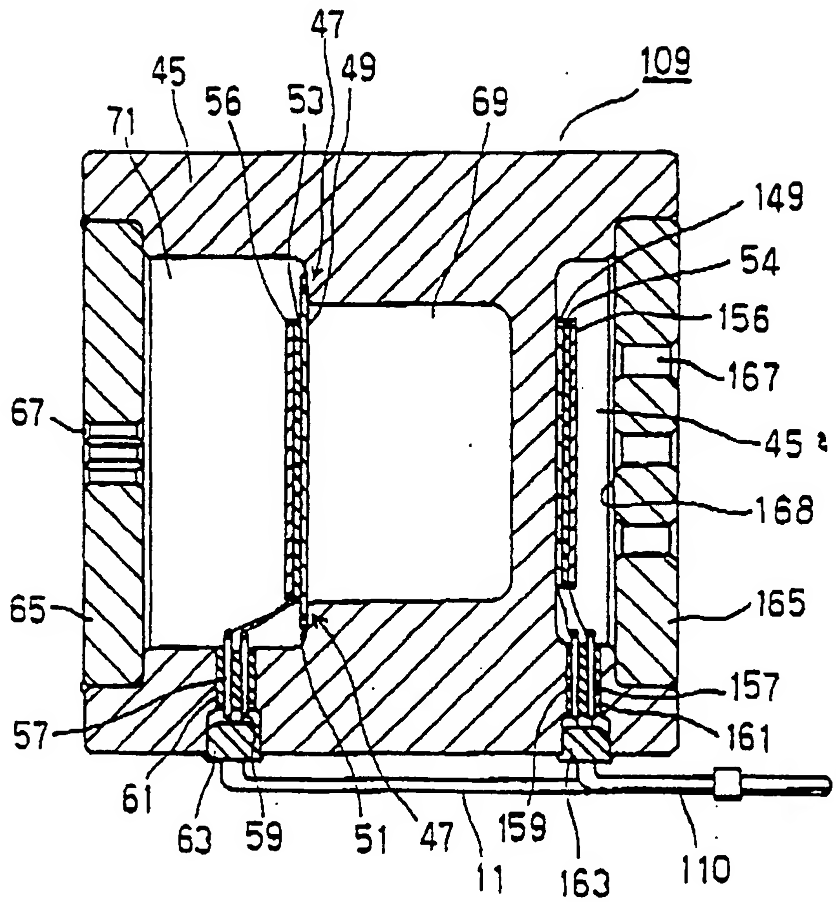

47
45
49
109
56
53
71
69
149
54
156
167
67
45
168
65
165
157
57
161
61
63
59
51
47
159
11
163
110

FIG.32

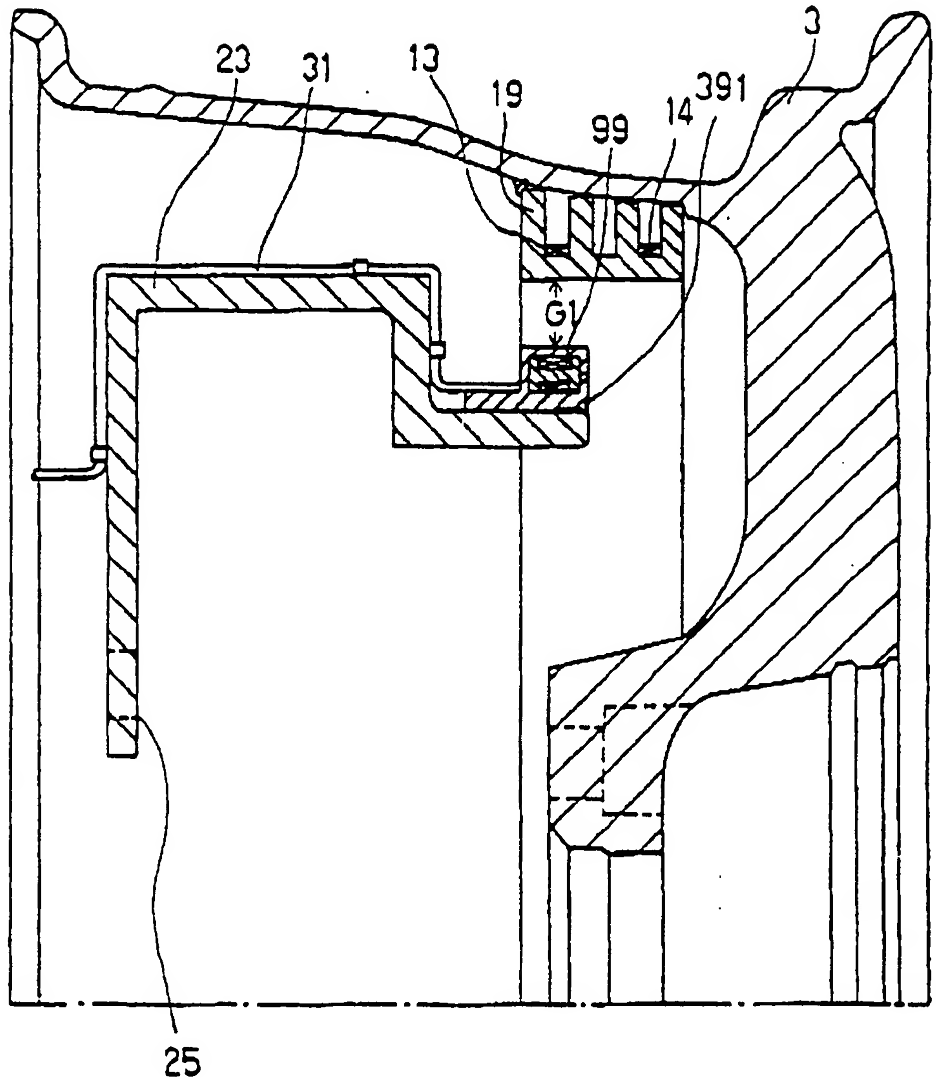


FIG.33

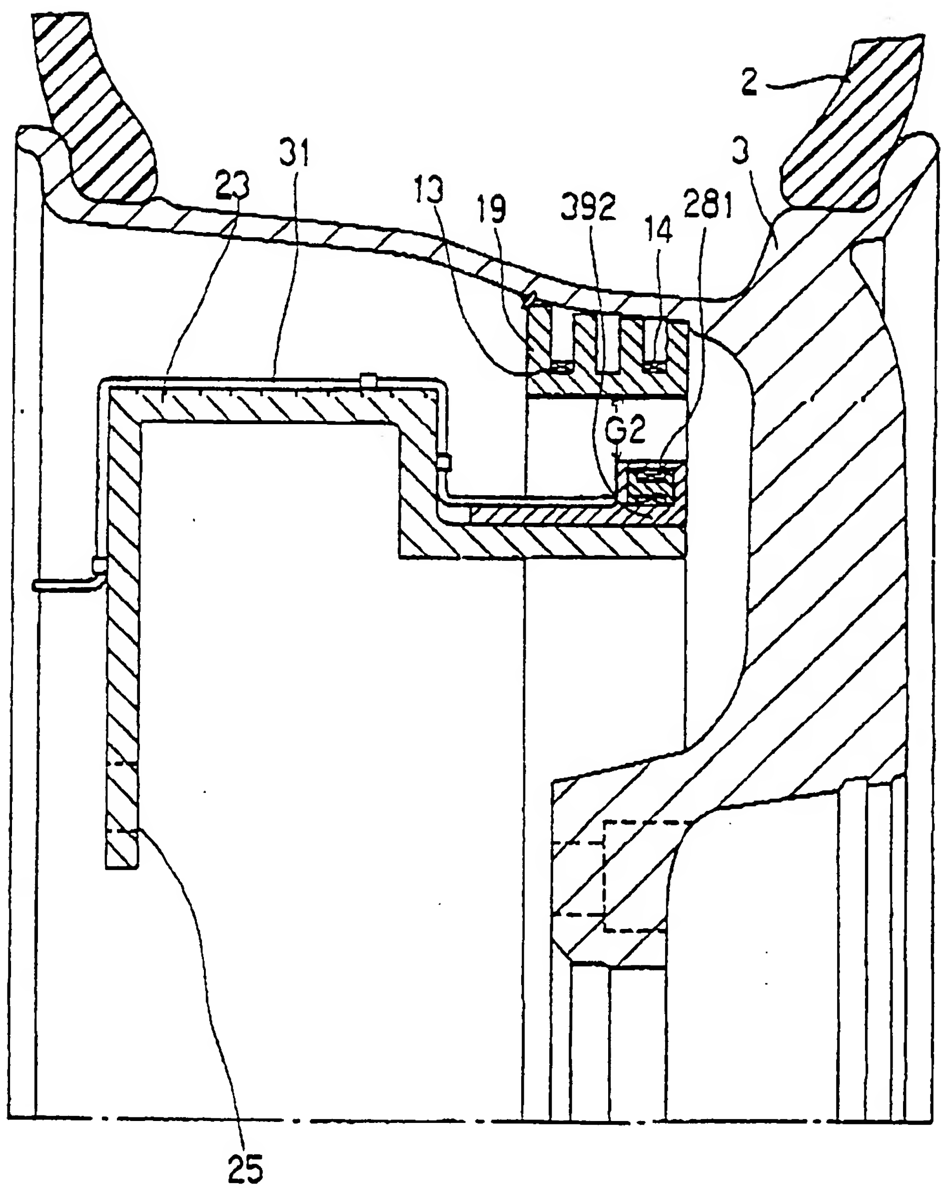


FIG.34(a)

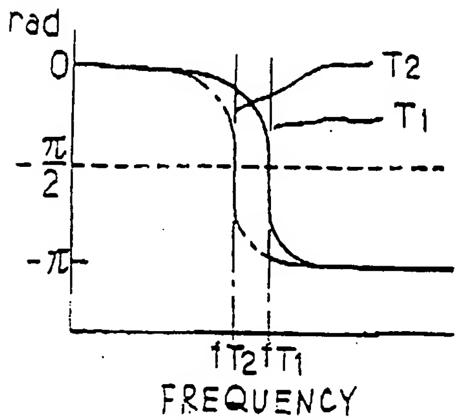


FIG.35(a)

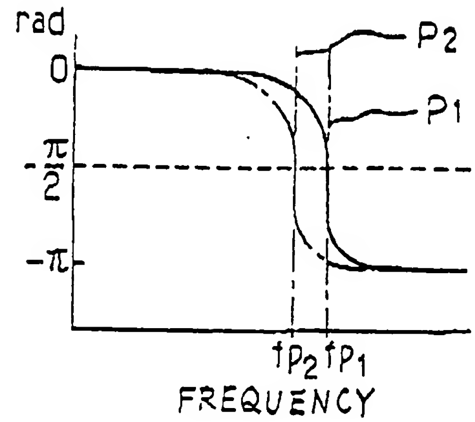


FIG.34(b)

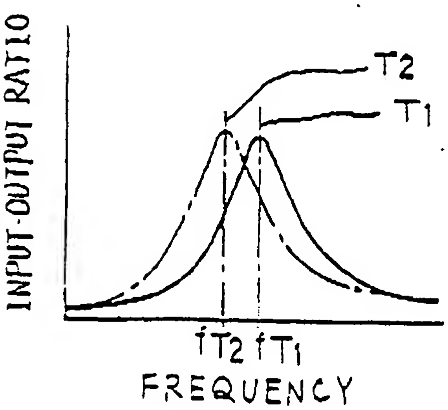


FIG.35(b)

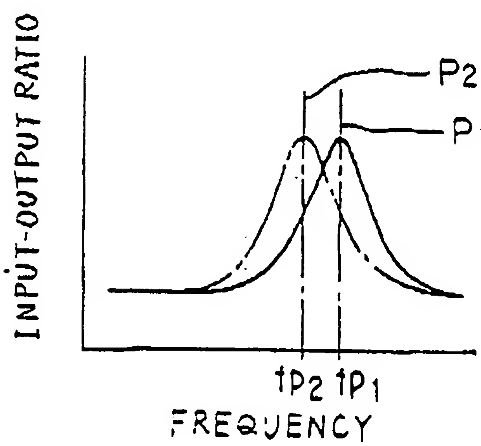


FIG.36

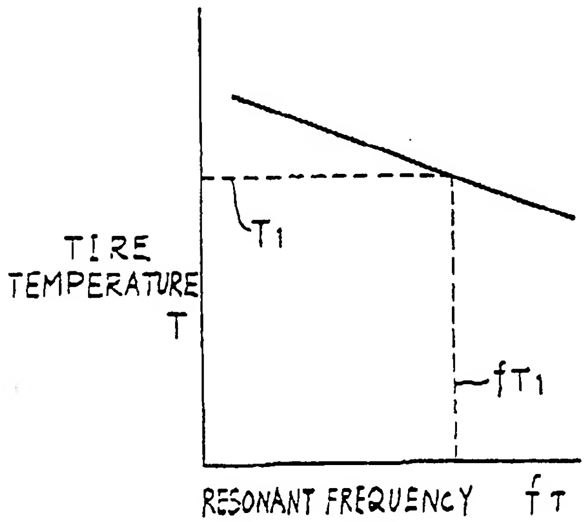

TIRE
TEMPERATURE
T
T1
fT1
RESONANT FREQUENCY fT

FIG.37

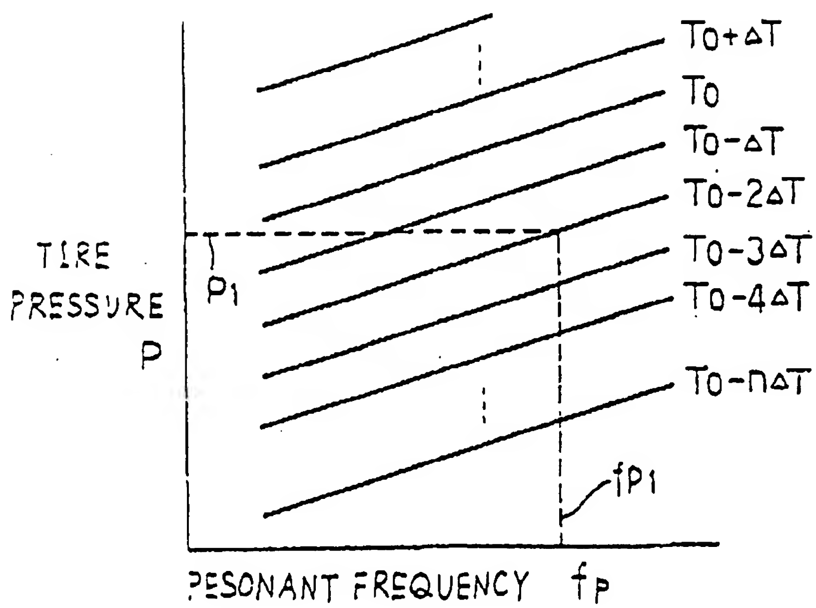

TIRE
PRESSURE
P
P1
fP1
To+ΔT
To
To-ΔT
To-2ΔT
To-3ΔT
To-4ΔT
To-nΔT
RESONANT FREQUENCY fP

FIG.38

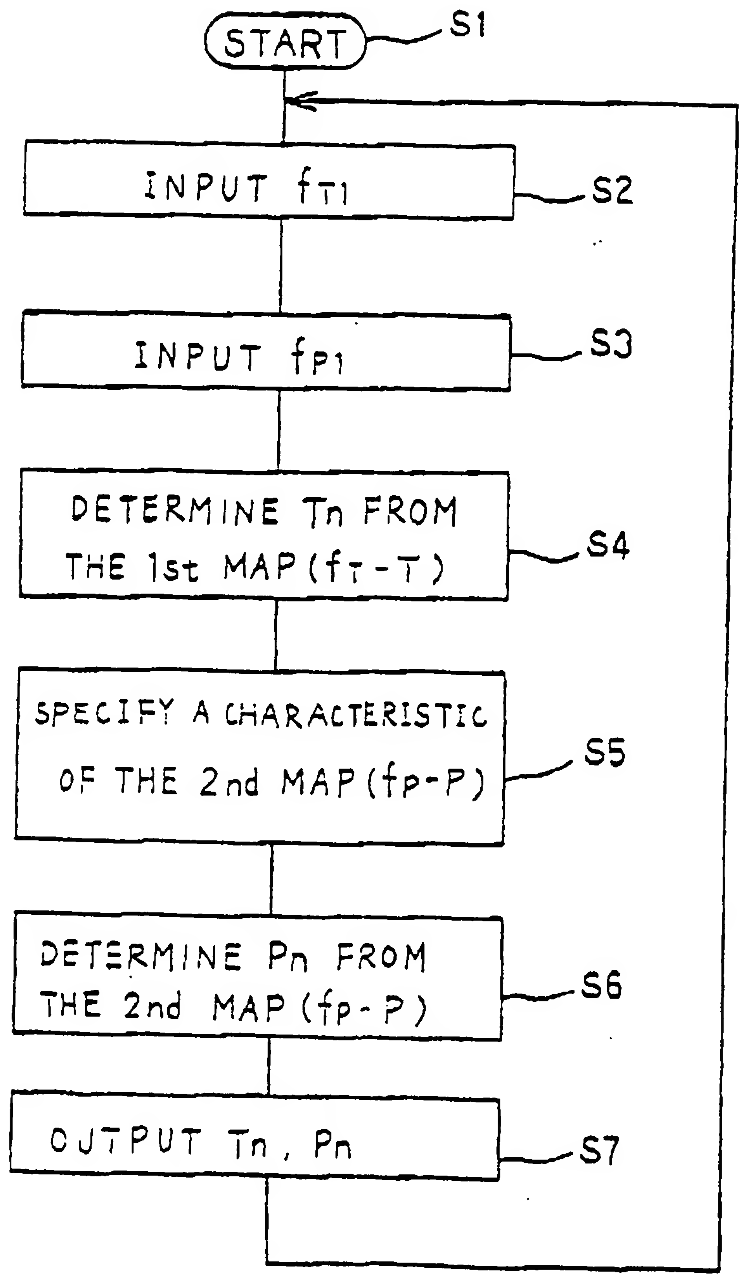

START
S1
INPUT fT1
S2
INPUT fP1
S3
DETERMINE Tn FROM THE 1st MAP (fT-T)
S4
SPECIFY A CHARACTERISTIC OF THE 2nd MAP (fP-P)
S5
DETERMINE Pn FROM THE 2nd MAP (fP-P)
S6
OUTPUT Tn, Pn
S7

FIG.39

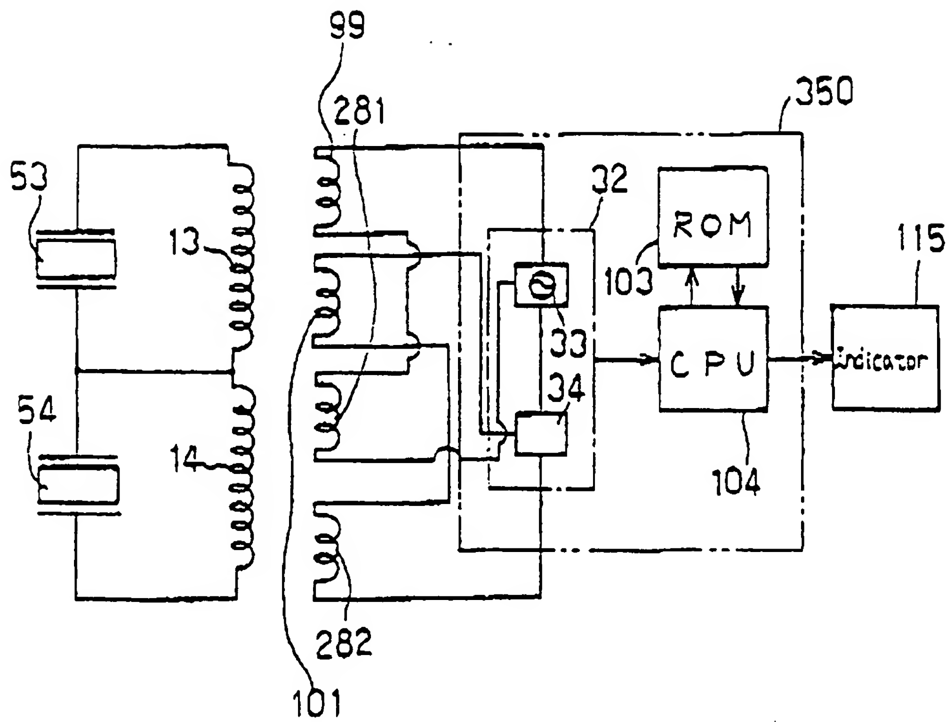

99
281
350
53
32
ROM
13
115
103
33
CPU
Indicator
34
54
14
104
282
101

FIG.40

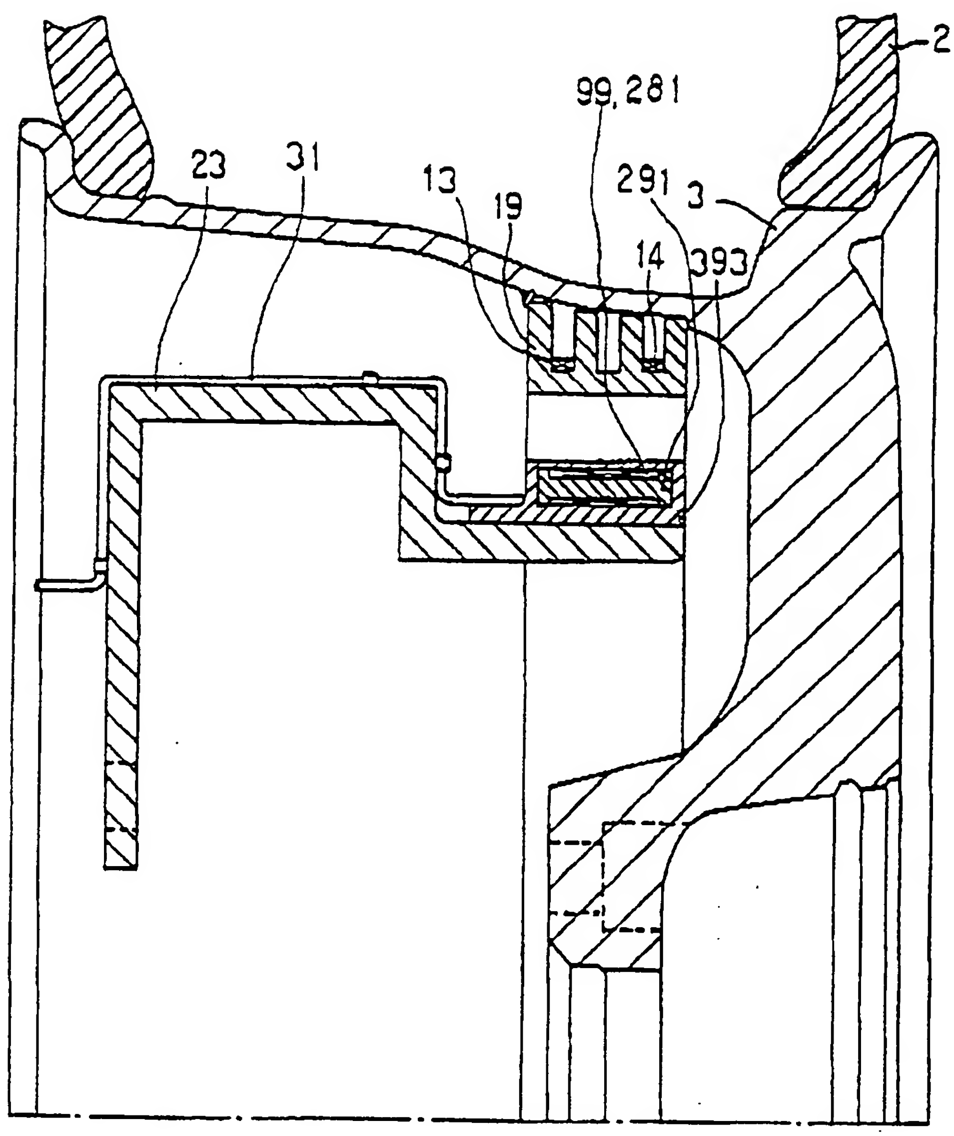


FIG. 41(a)

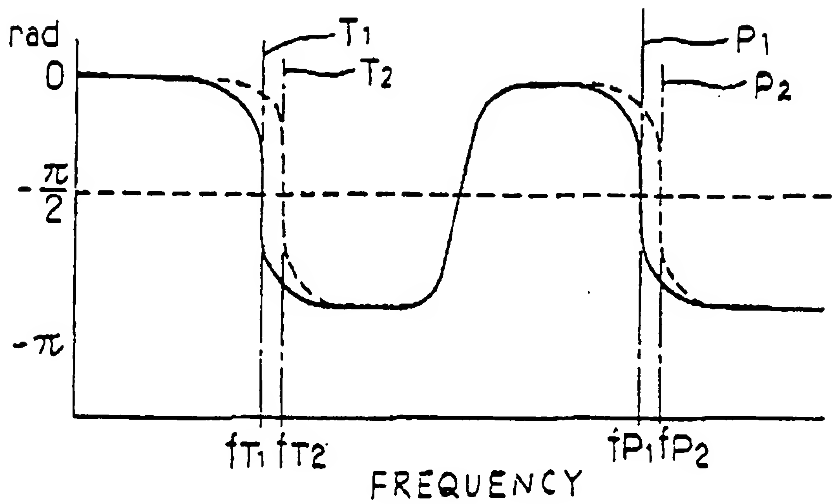


FIG. 41(b)

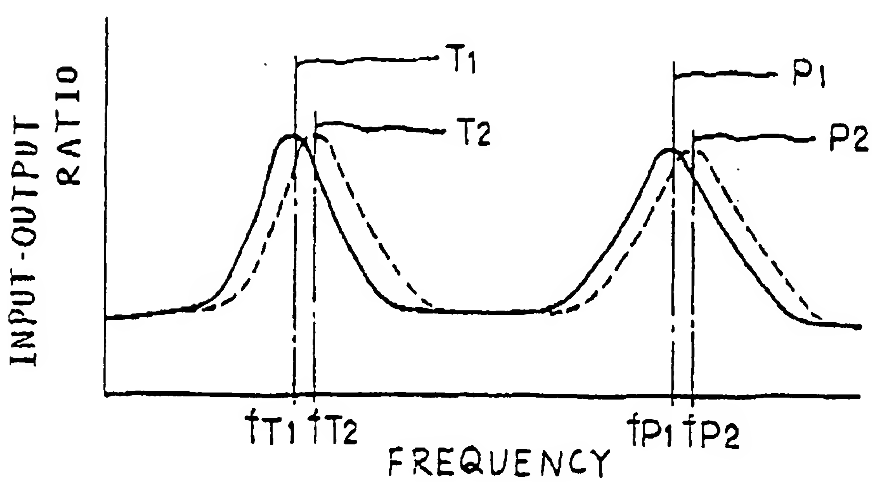


FIG.42

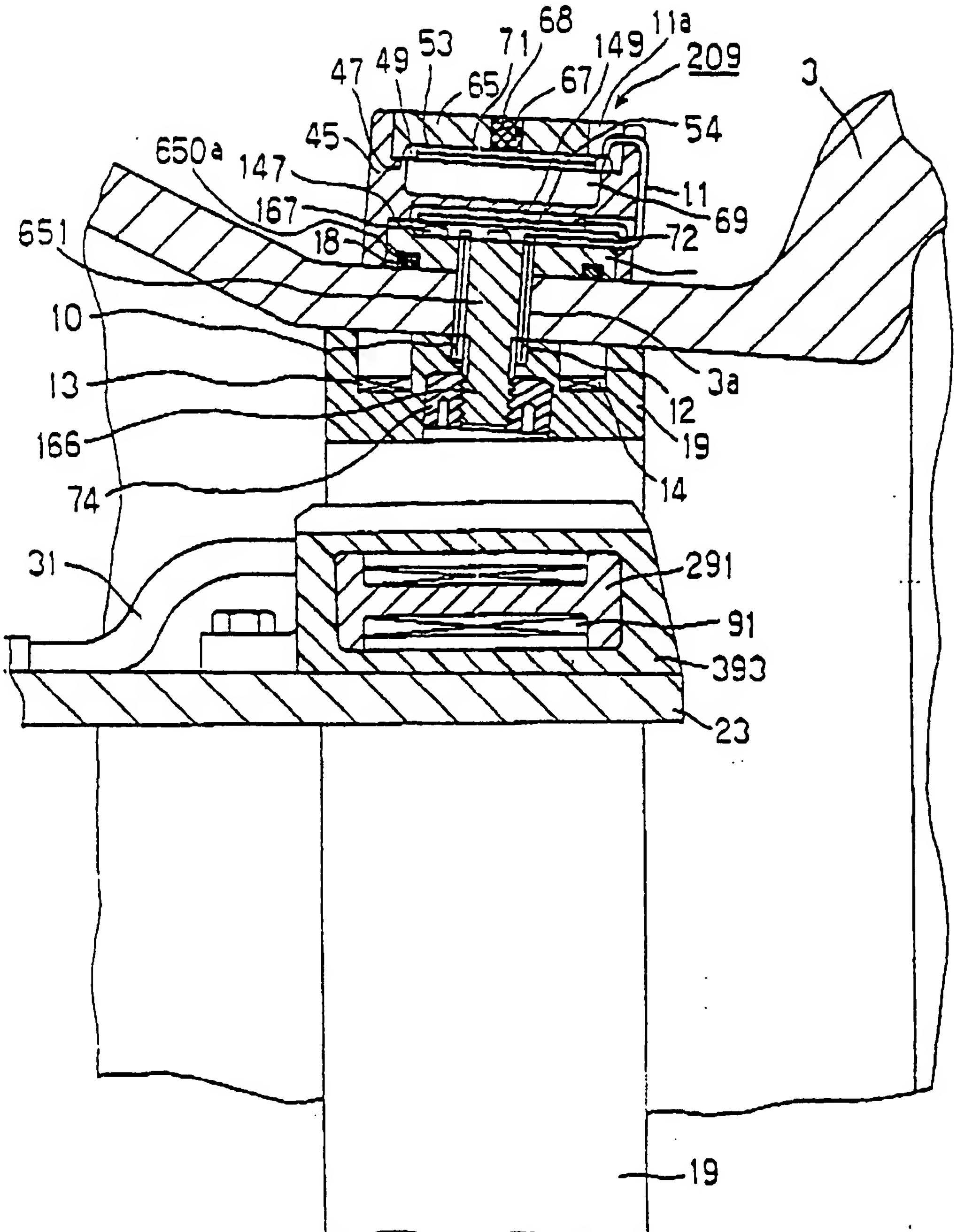

68
71
11a
149
53
209
47
49
65
67
3
54
45
650a
147
11
69
167
18
72
651
10
3a
13
12
19
166
14
74
31
291
91
393
23
19

FIG.43

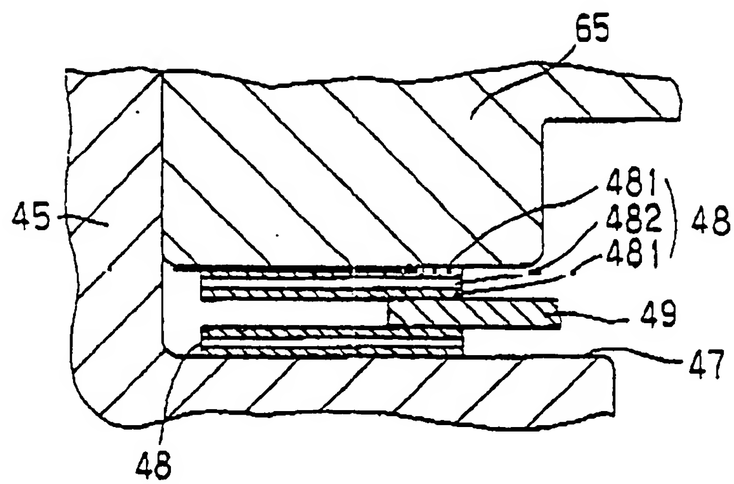


FIG.47

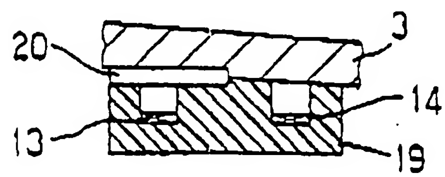


FIG.44

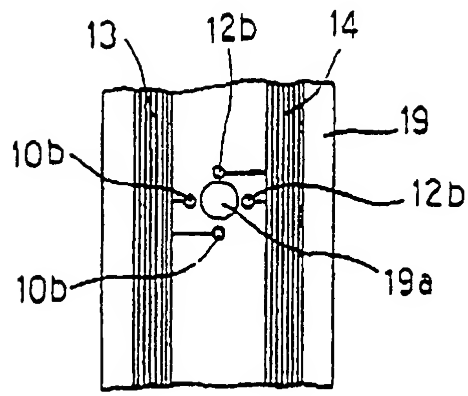


FIG.45

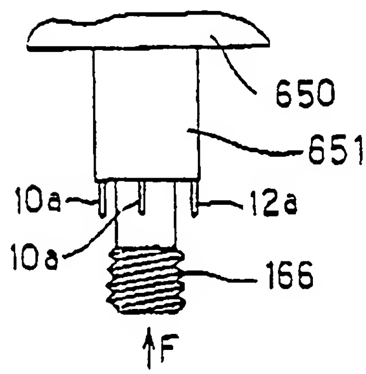


FIG.46

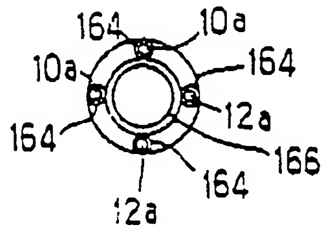


FIG.48

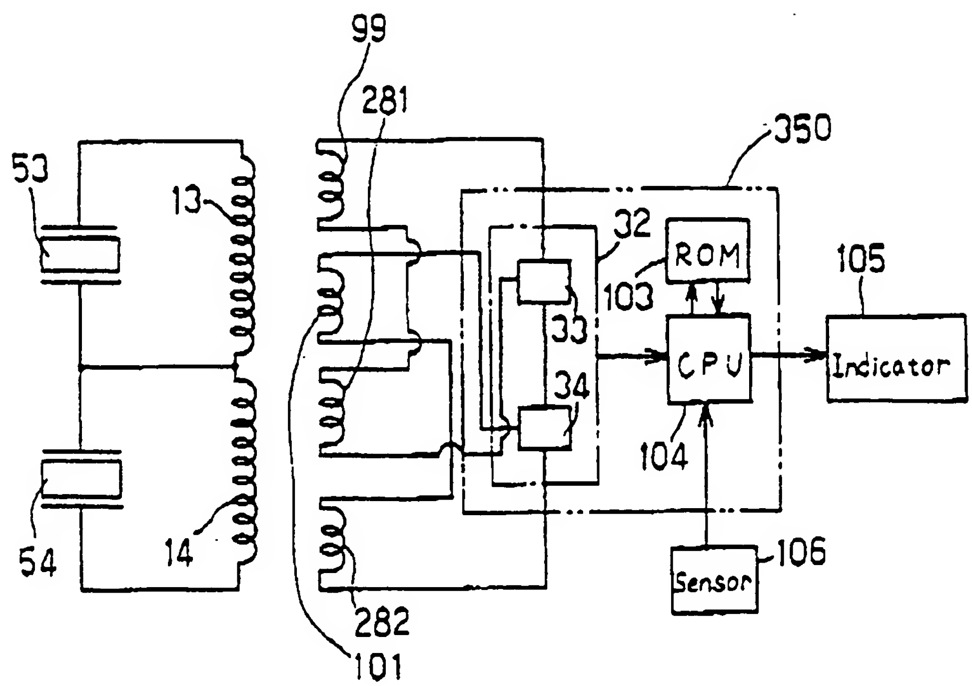
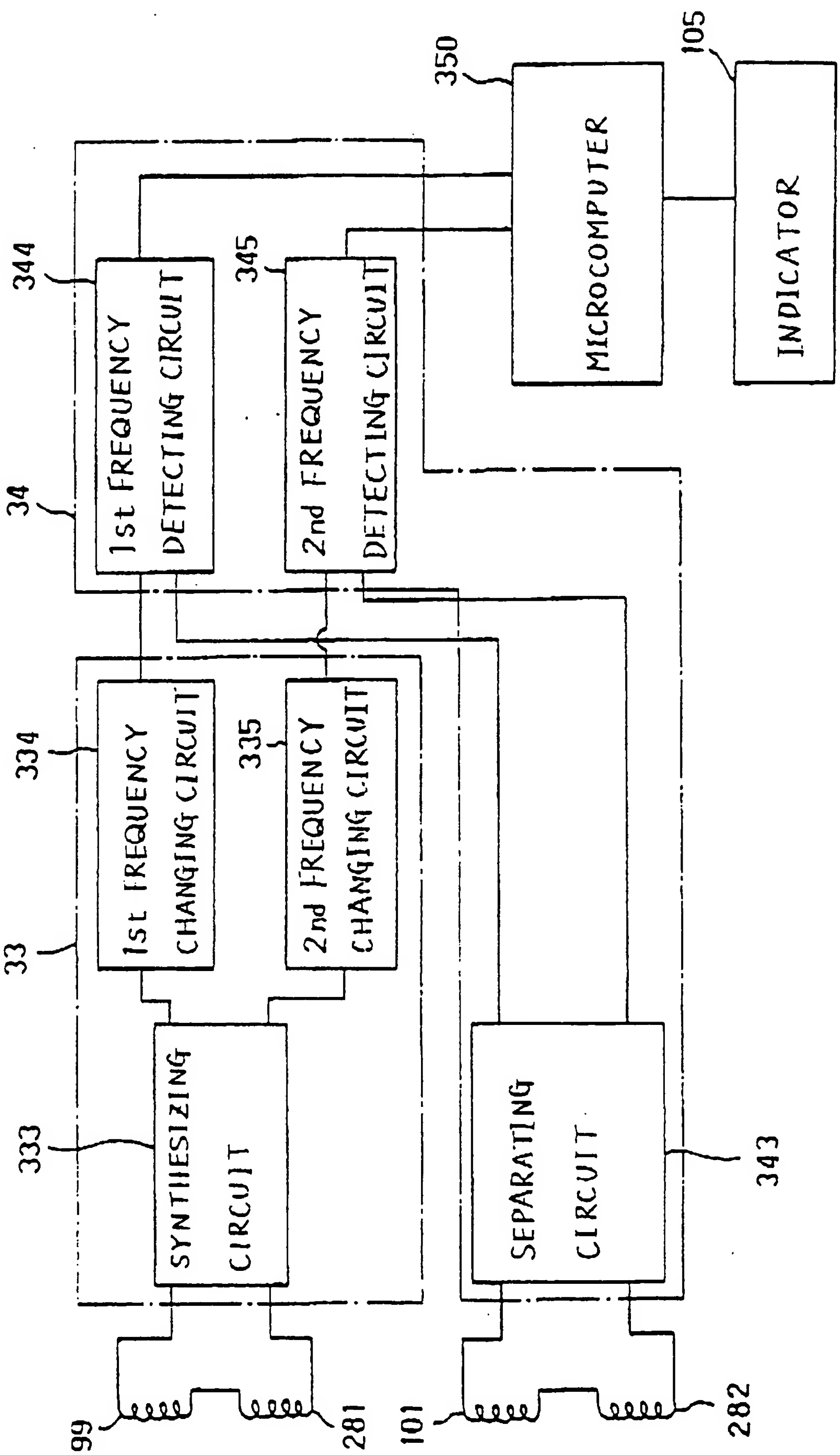

99
281
350
53
13
32
ROM
103
105
33
CPU
Indicator
34
104
54
14
106
Sensor
282
101

FIG.49



350
105
MICROCOMPUTER
INDICATOR
344
345
1st FREQUENCY DETECTING CIRCUIT
2nd FREQUENCY DETECTING CIRCUIT
34
334
335
1st FREQUENCY CHANGING CIRCUIT
2nd FREQUENCY CHANGING CIRCUIT
33
333
SYNTHESIZING CIRCUIT
SEPARATING CIRCUIT
343
99
281
101
282

FIG.50

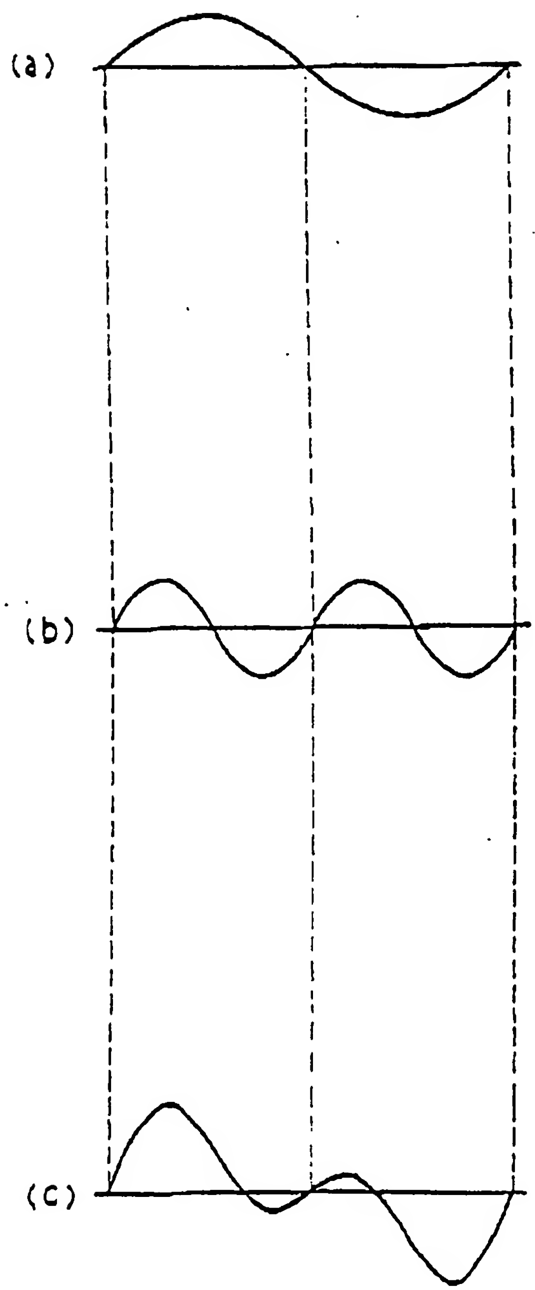


FIG.51

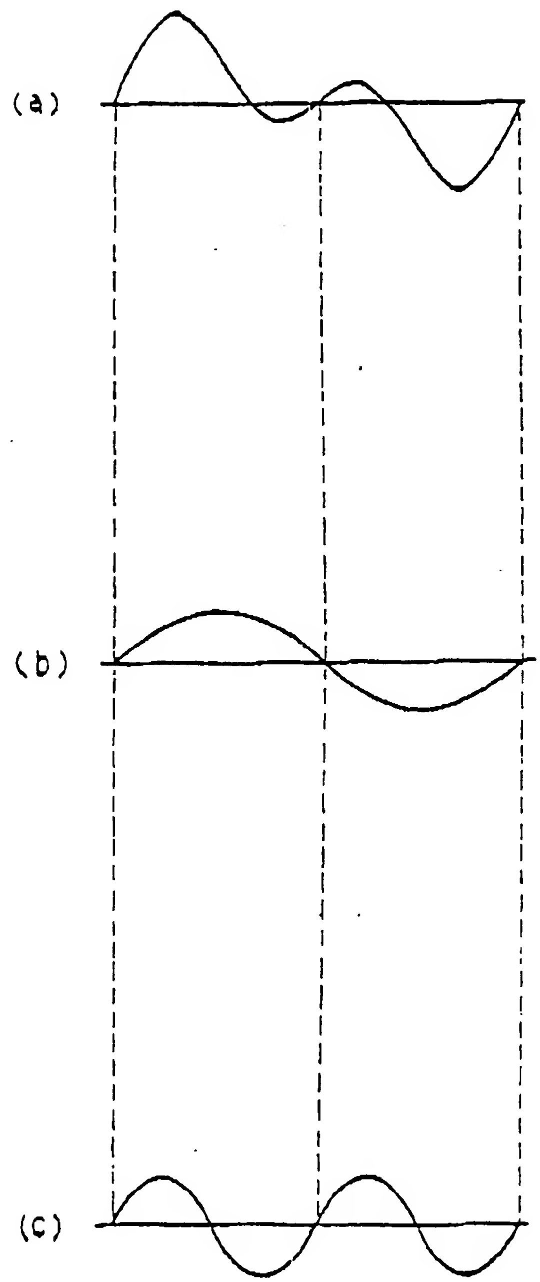


FIG.52

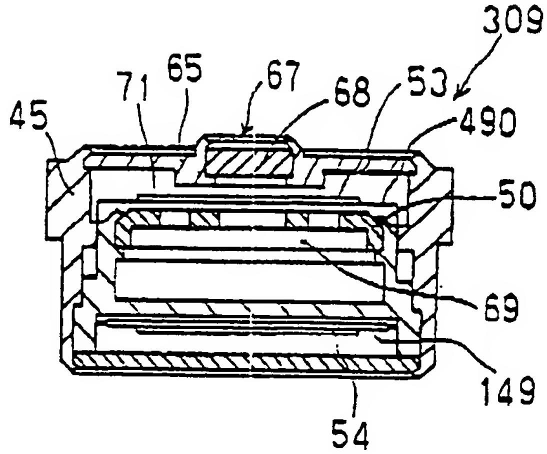

309
71
65
67
68
53
45
490
50
69
149
54

FIG.53

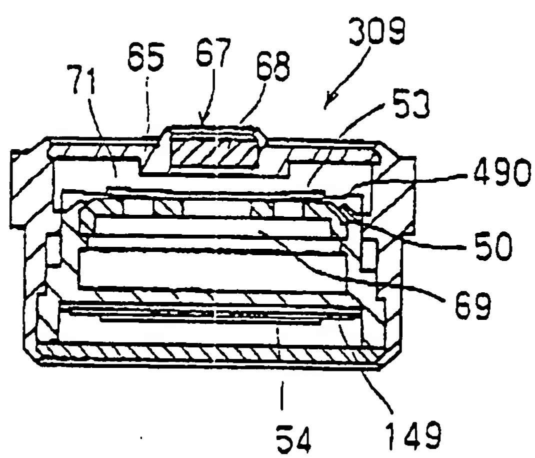

309
65
67
68
71
53
490
50
69
54
149

FIG.1

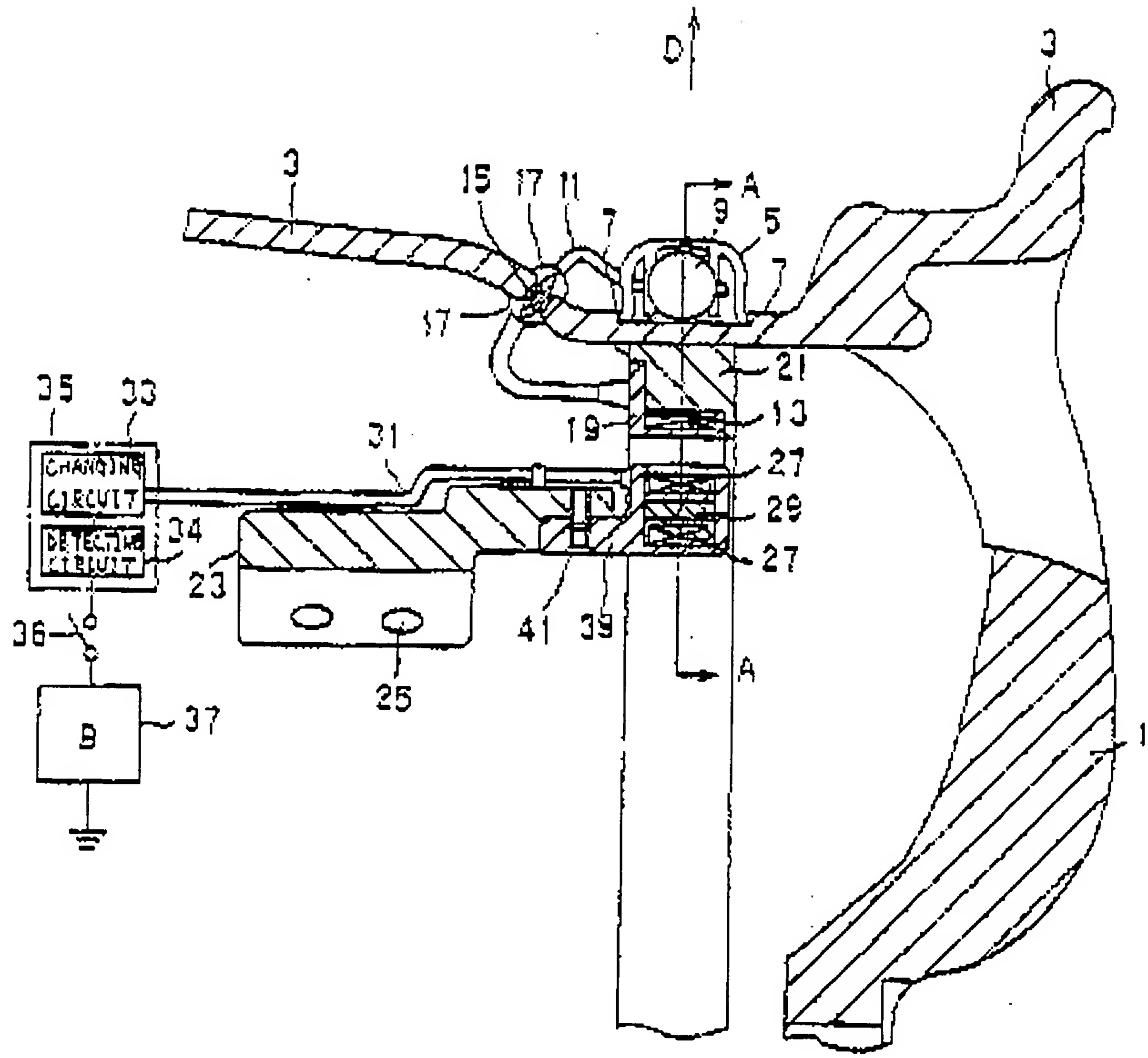

D
3
3
15
17
11
7
9
5
7
A
17
21
35
33
13
19
31
27
CHANGING CIRCUIT
29
DETECTING CIRCUIT
34
27
23
41
39
36
25
A
B
37
1

FIG.2

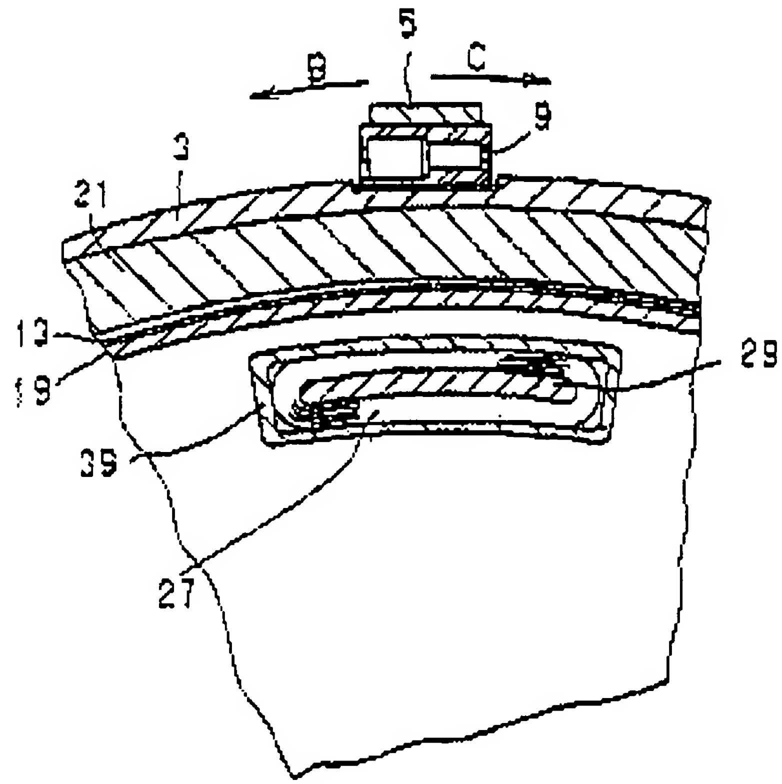


FIG.3

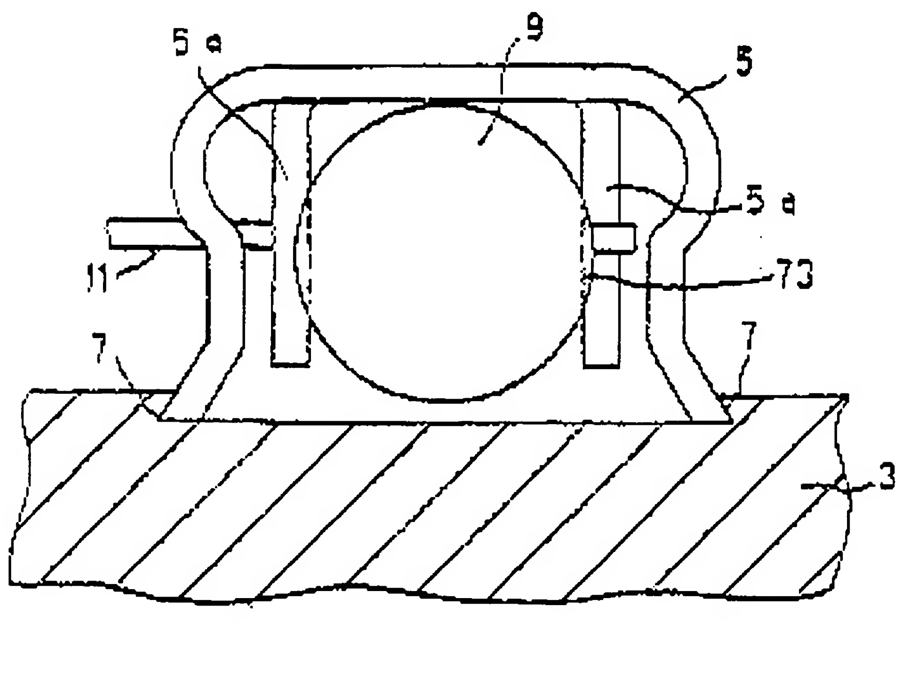


FIG.4

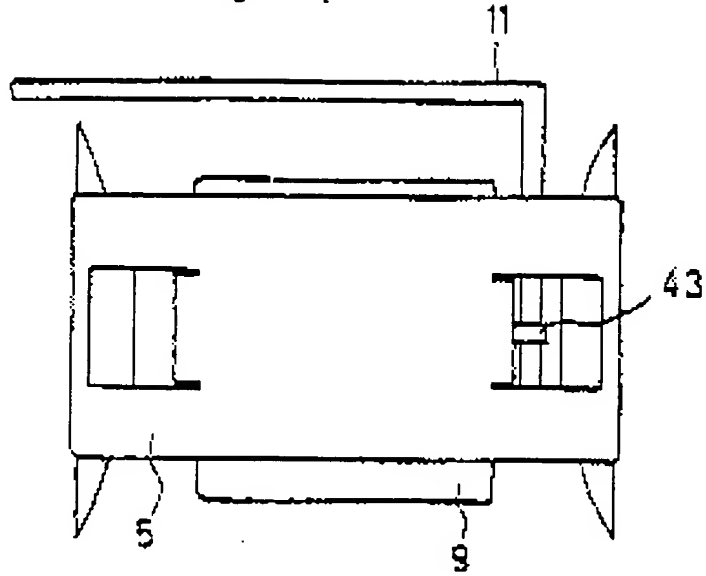

11
43
5
9

FIG.5

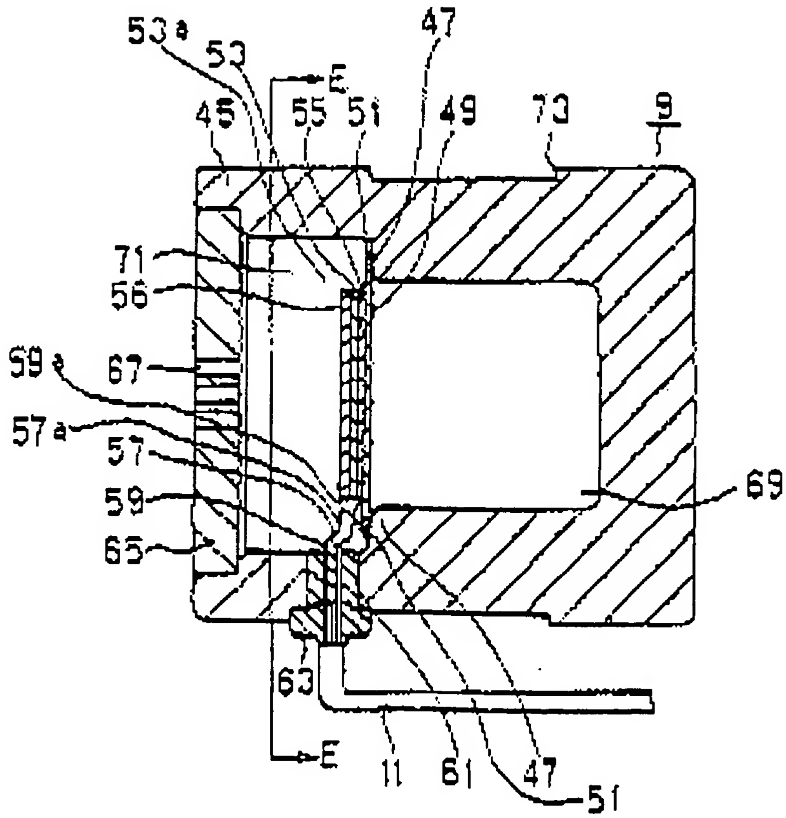

53a
53
47
E
45
55
51
49
73
9
71
56
59a
67
57a
57
69
59
65
63
E
11
61
47
51

FIG.6

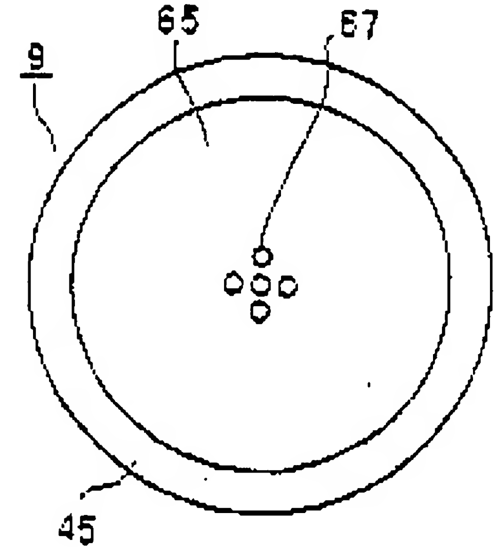


FIG.7

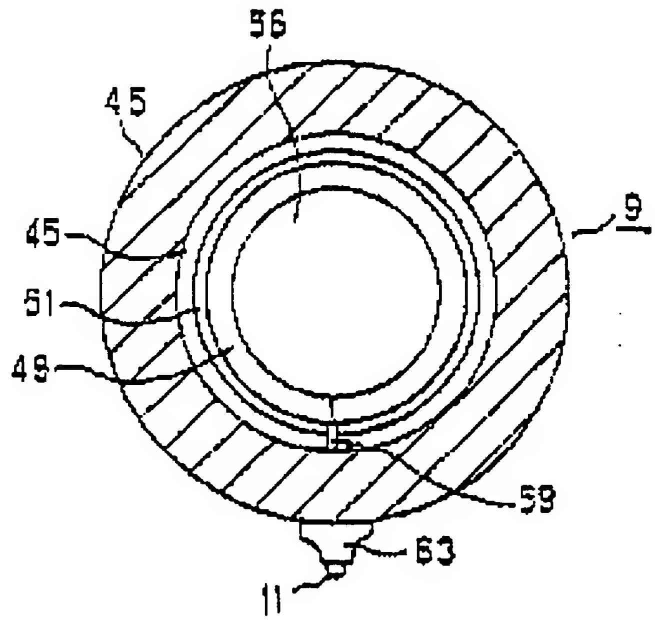


FIG.8

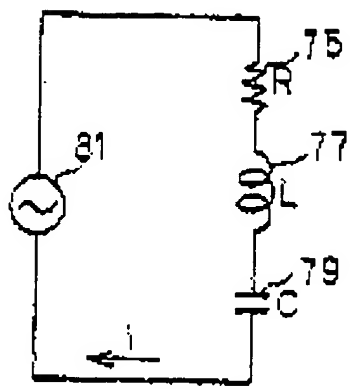


FIG.9

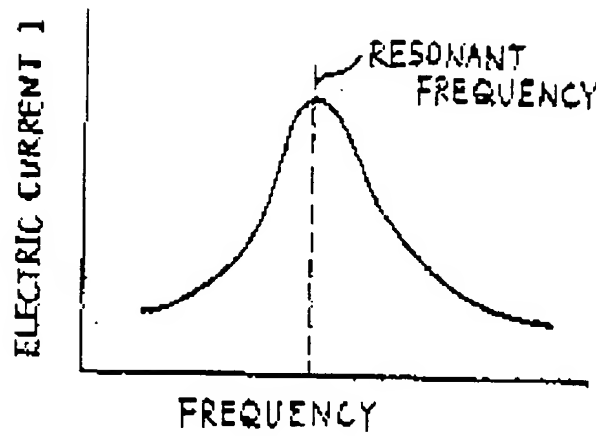


FIG.10

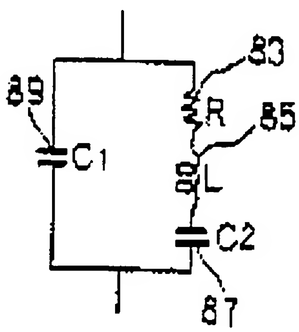


FIG.11

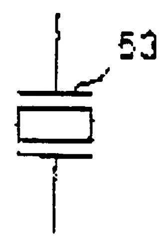


FIG.12

FIG.13

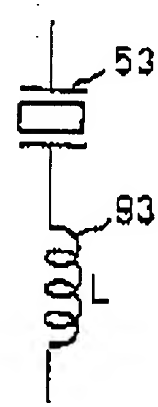


FIG.14

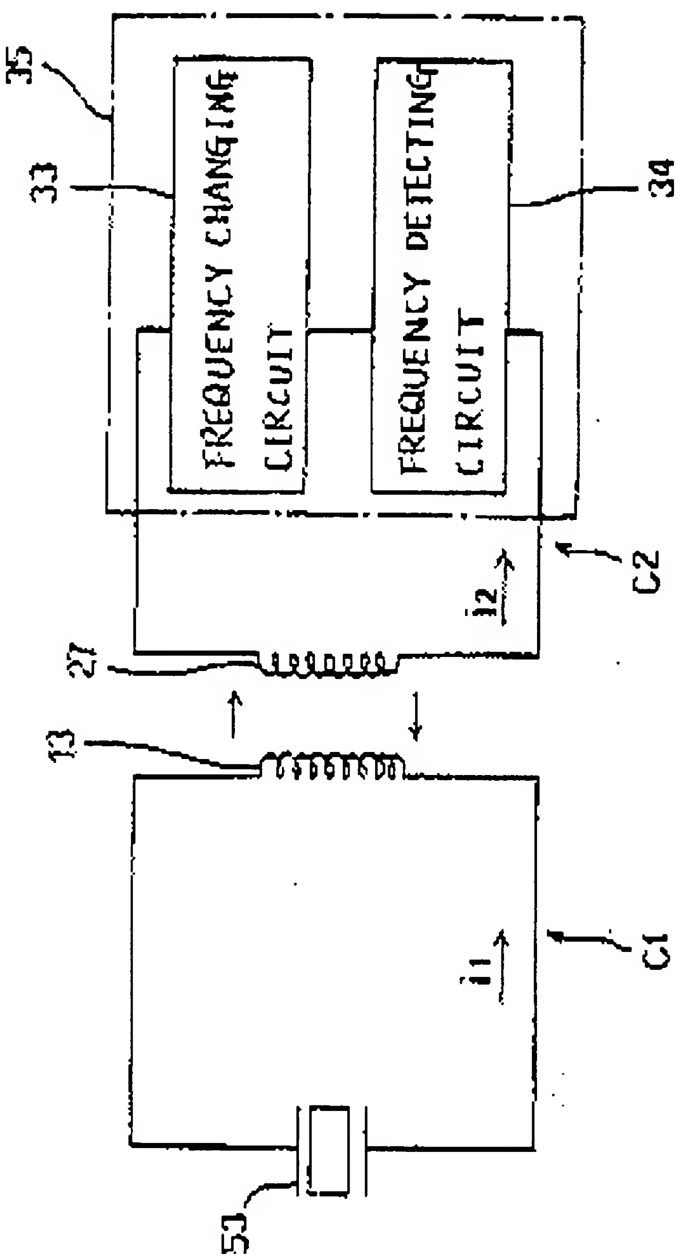

35
33
FREQUENCY CHANGING CIRCUIT
FREQUENCY DETECTING CIRCUIT
34
27
13
i2
C2
i1
C1
53

FIG.15

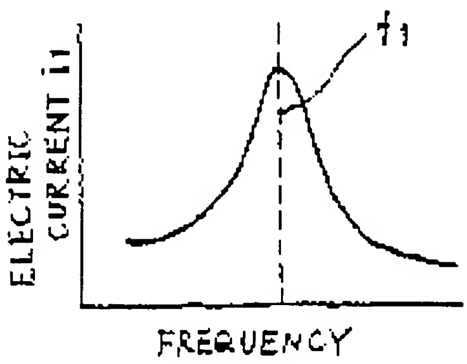

ELECTRIC CURRENT i1
FREQUENCY

FIG.16

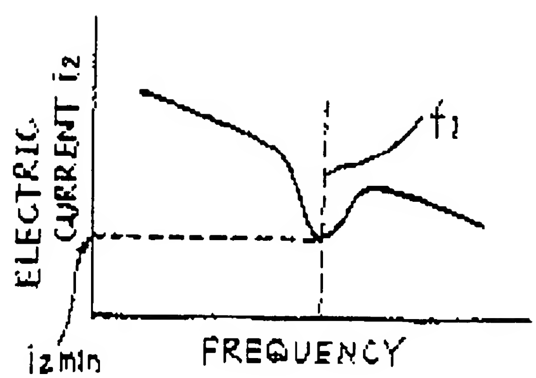

ELECTRIC CURRENT i2
i2min
FREQUENCY

FIG.17

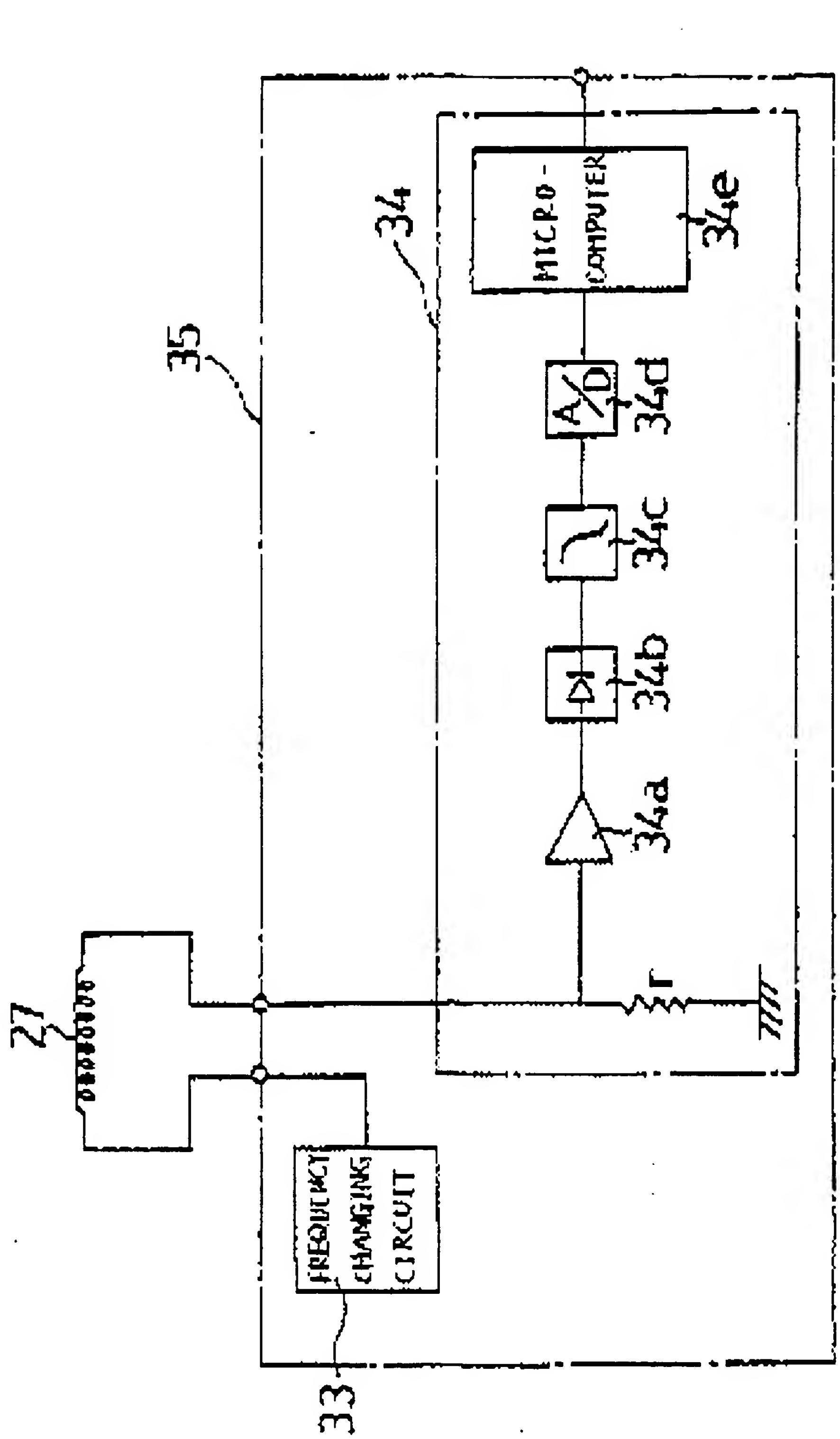

35
34
MICRO-COMPUTER
34e
A/D
34d
34c
34b
34a
r
27
FREQUENCY CHANGING CIRCUIT
33

FIG.18

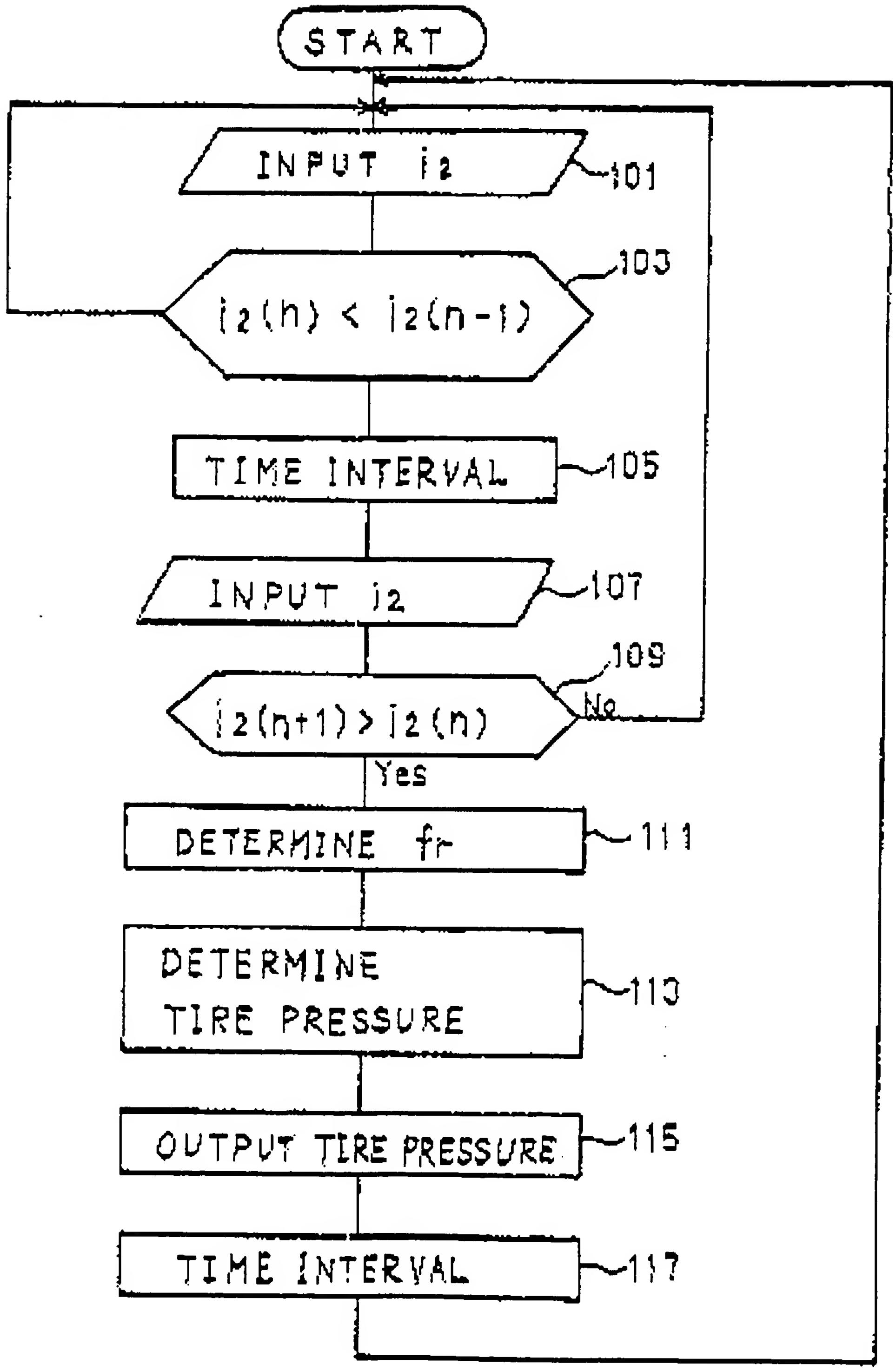

START
INPUT i2
101
i2(n) < i2(n-1)
103
TIME INTERVAL
105
INPUT i2
107
109
i2(n+1) > i2(n)
No
Yes
DETERMINE fr
111
DETERMINE
TIRE PRESSURE
113
OUTPUT TIRE PRESSURE
115
TIME INTERVAL
117

FIG.19

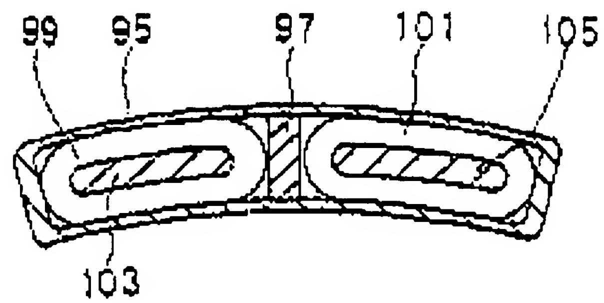


FIG.22

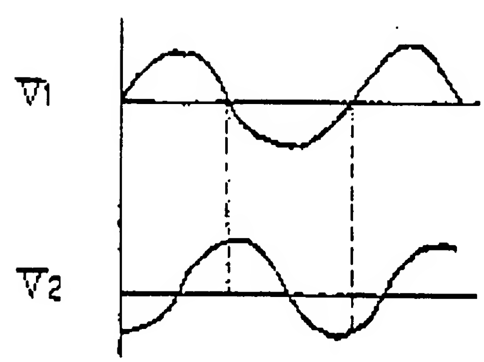


FIG.20

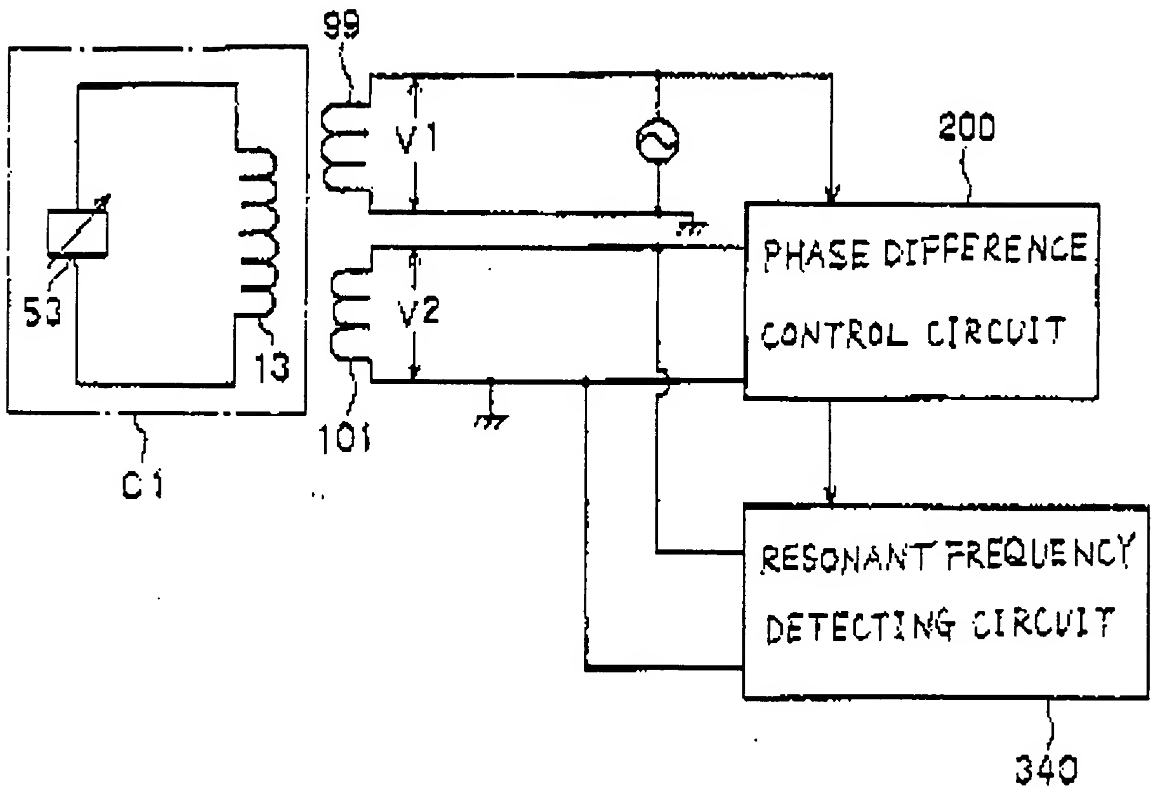

99
V1
200
PHASE DIFFERENCE CONTROL CIRCUIT
53
V2
13
101
C1
RESONANT FREQUENCY DETECTING CIRCUIT
340

FIG.21

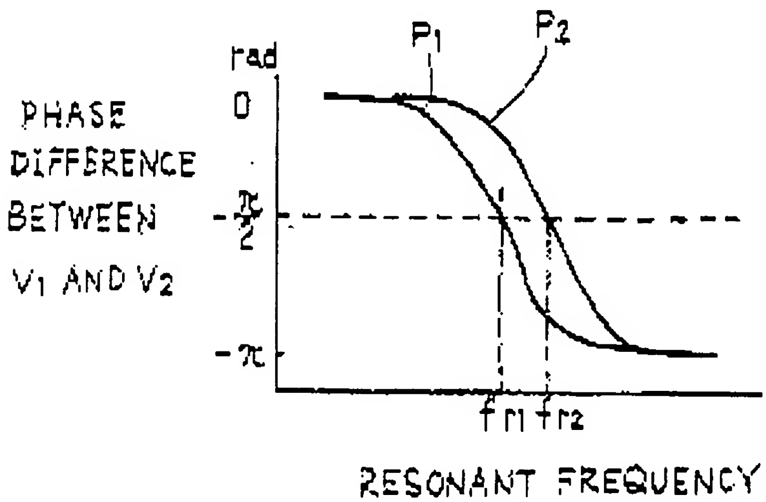

P1
P2
rad
0
PHASE DIFFERENCE BETWEEN V1 AND V2
-π/2
-π
fr1 fr2
RESONANT FREQUENCY

FIG. 23

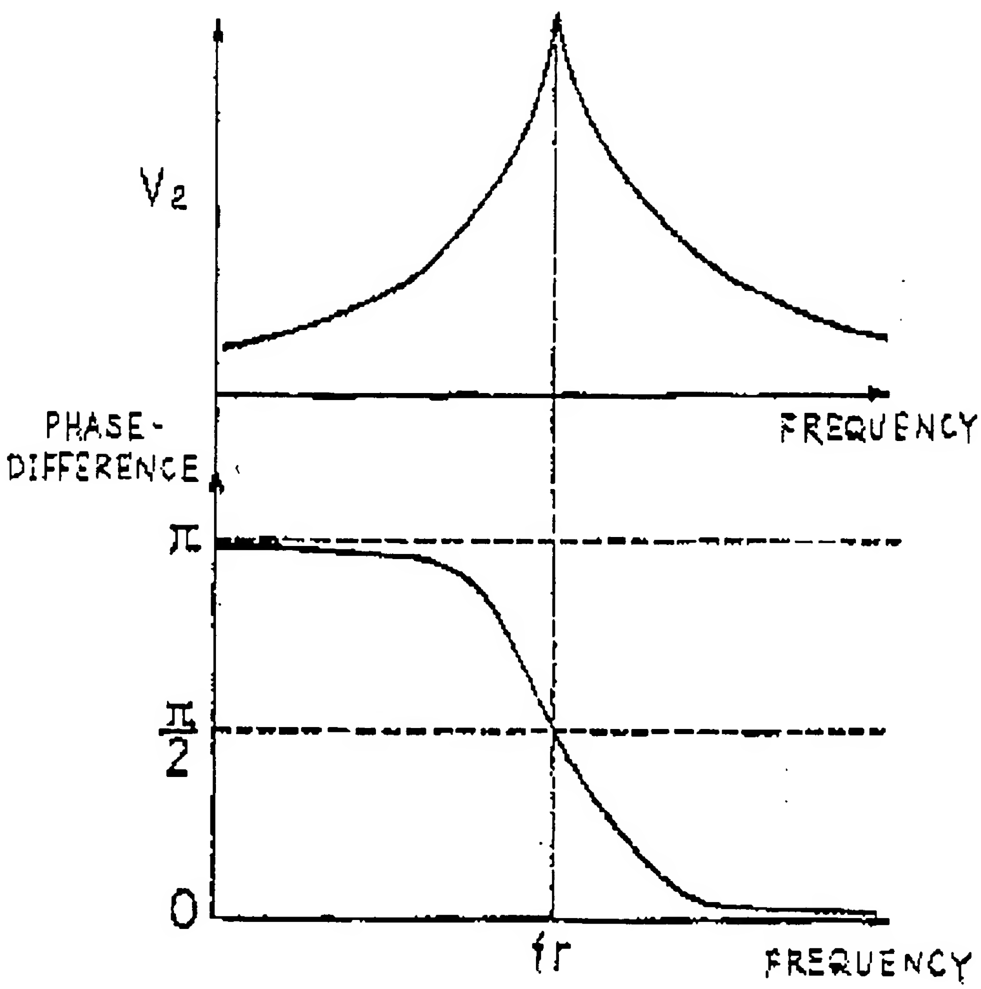


FIG.24

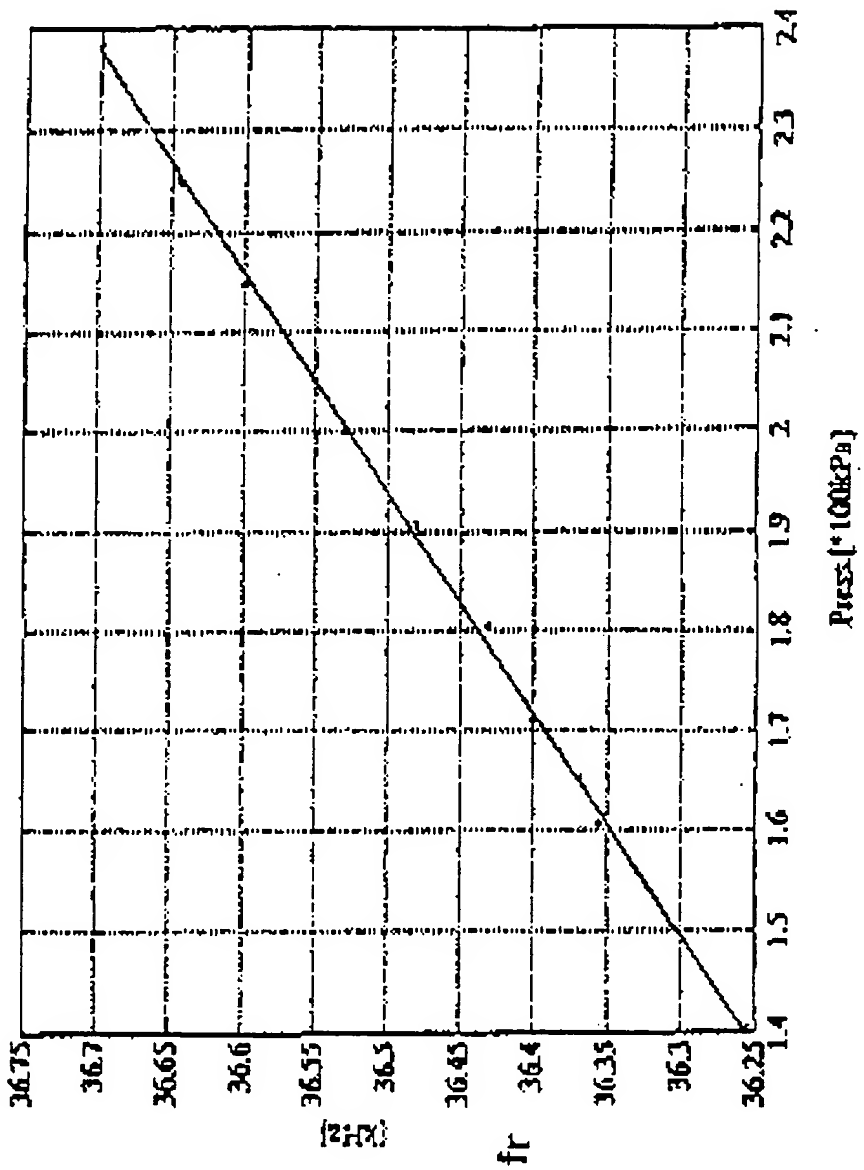

fr
(KHz)
36.25
36.3
36.35
36.4
36.45
36.5
36.55
36.6
36.65
36.7
36.75
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
Press[*100kPa]

FIG.25

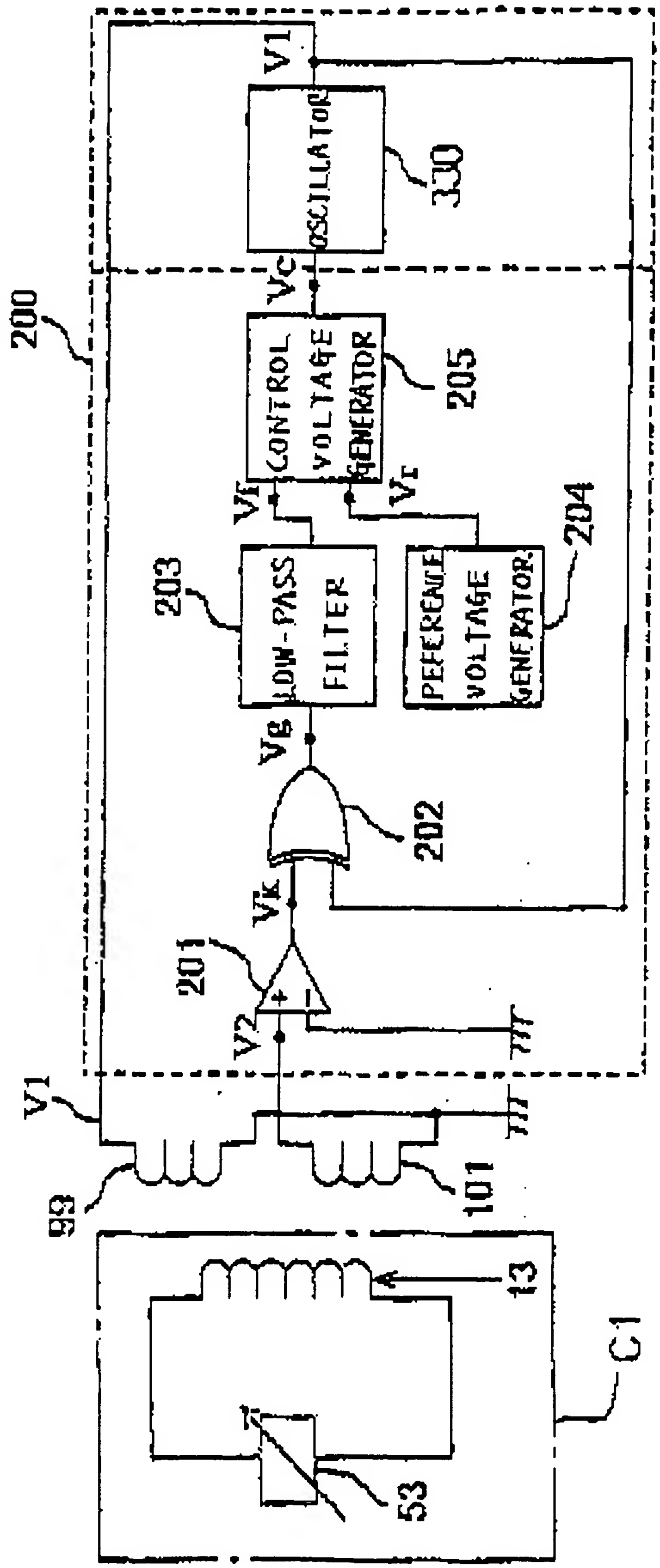

OSCILLATOR
330
CONTROL VOLTAGE GENERATOR
205
LOW-PASS FILTER
203
PEFERENCE VOLTAGE GENERATOR
204
200
202
201
V1
Vc
Vf
Vr
VB
VK
V2
99
101
13
53
C1

FIG. 26

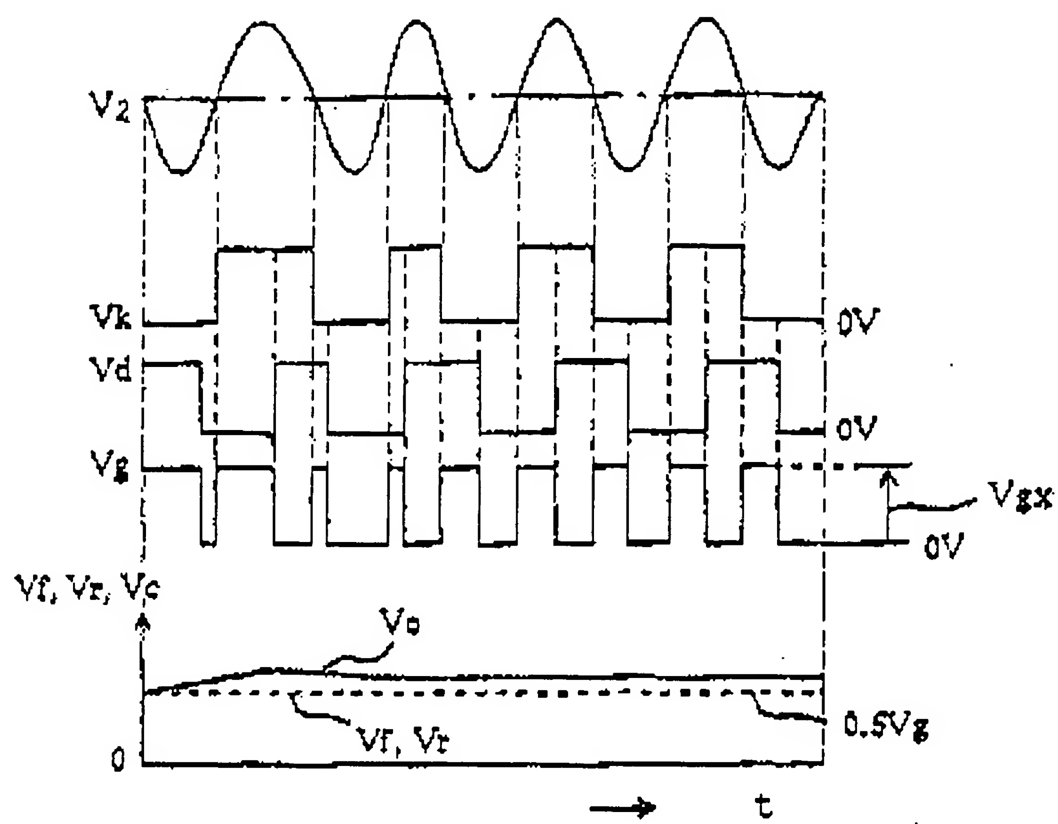


FIG. 27

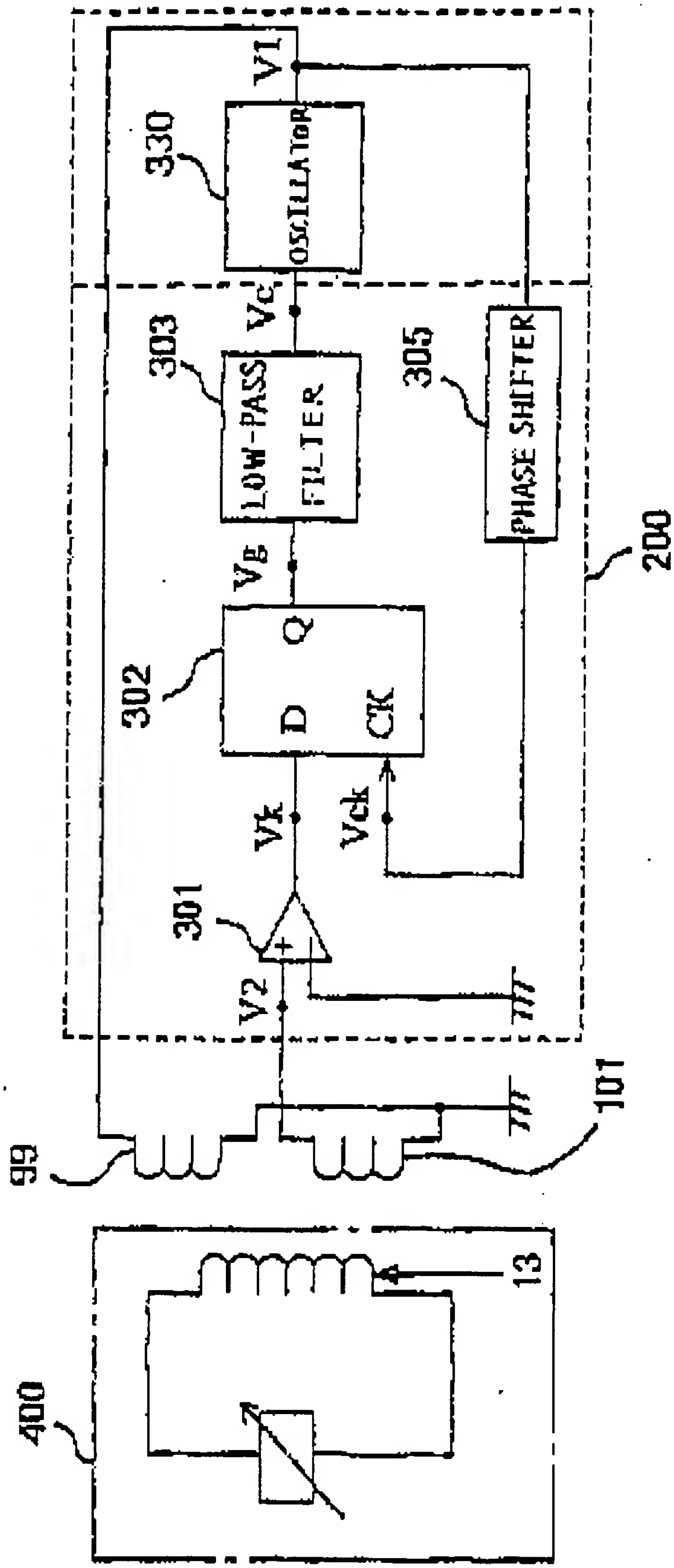

V1
330
OSCILLATOR
Vc
303
LOW-PASS FILTER
305
PHASE SHIFTER
VB
302
D
Q
CK
200
Vk
Vck
301
V2
99
101
13
400

FIG.28

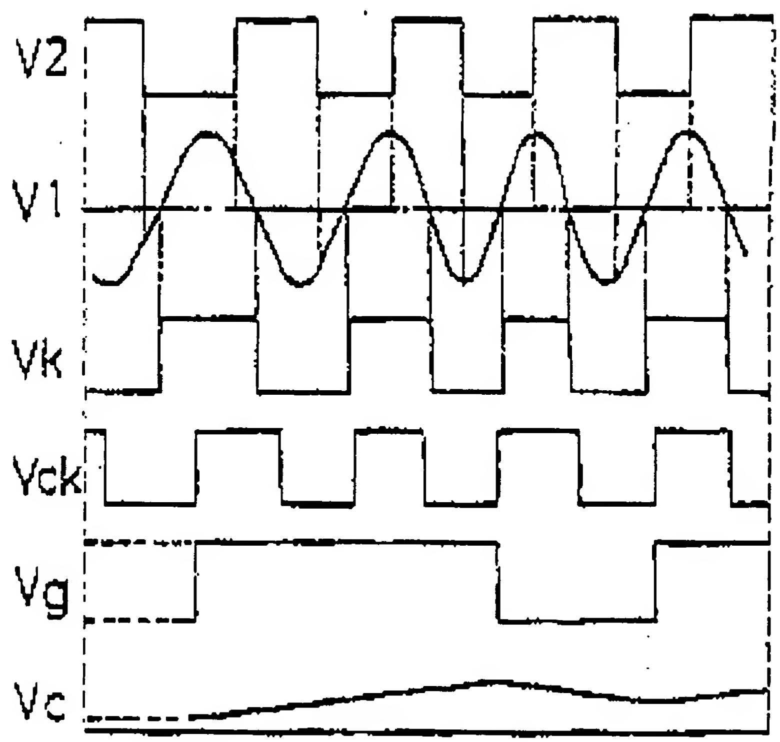


FIG.29

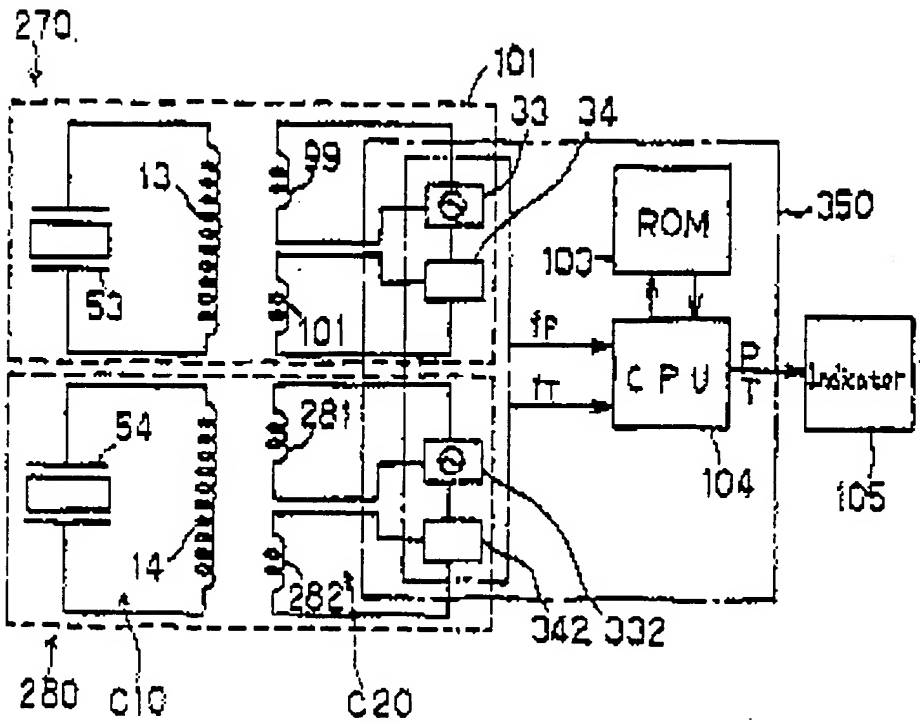

270
101
33
34
99
13
350
ROM
103
53
101
fP
fT
C P U
P
T
Indicator
54
281
104
105
14
282
342
332
280
C10
C20

FIG.30

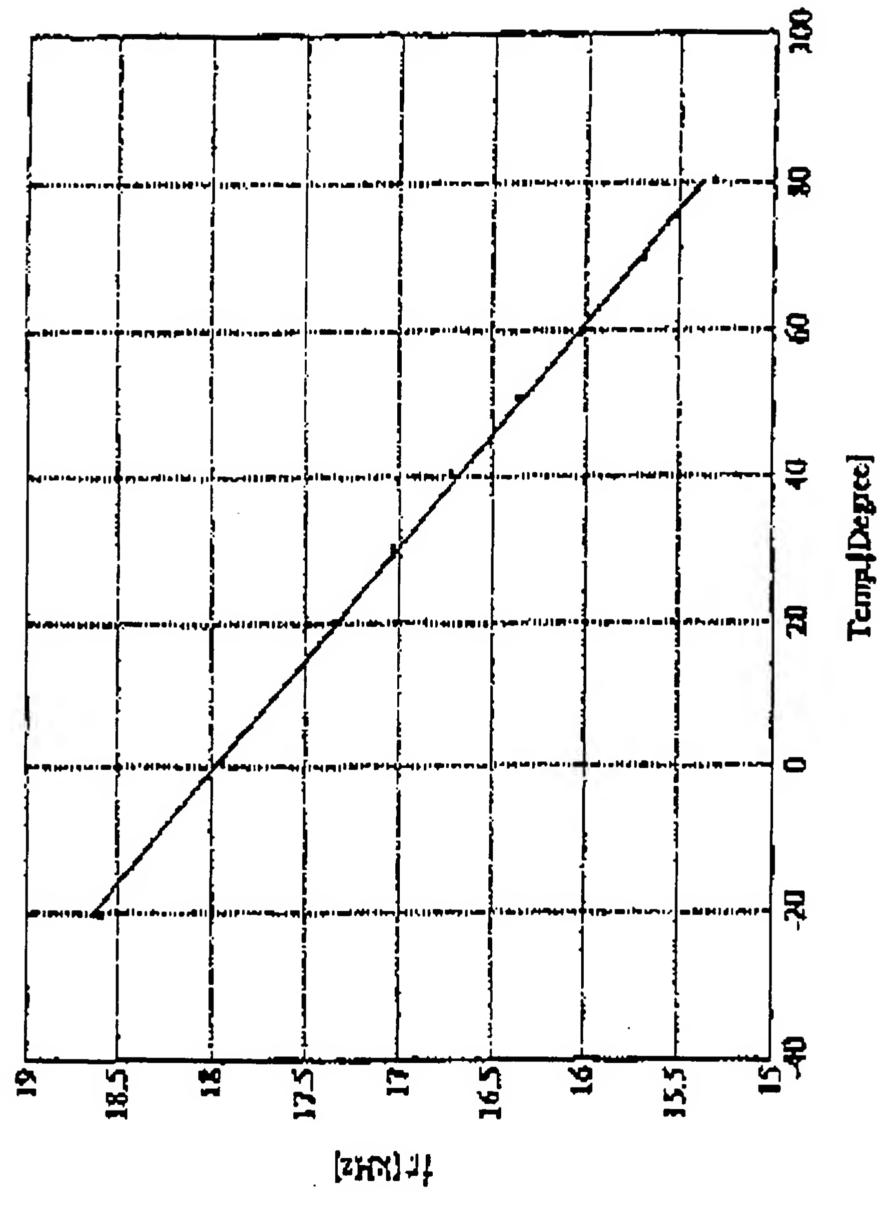


FIG.31

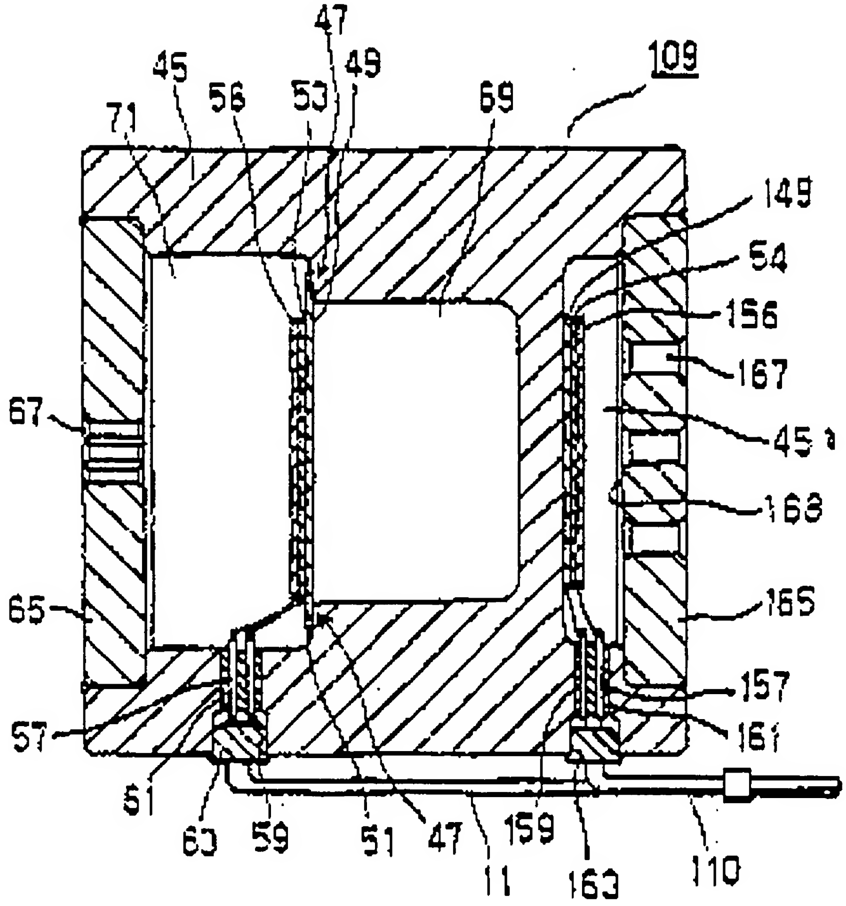

109
47
45
49
56
53
71
69
149
54
156
167
67
45a
168
65
165
157
57
161
51
159
63
59
51
47
11
163
110

FIG.32

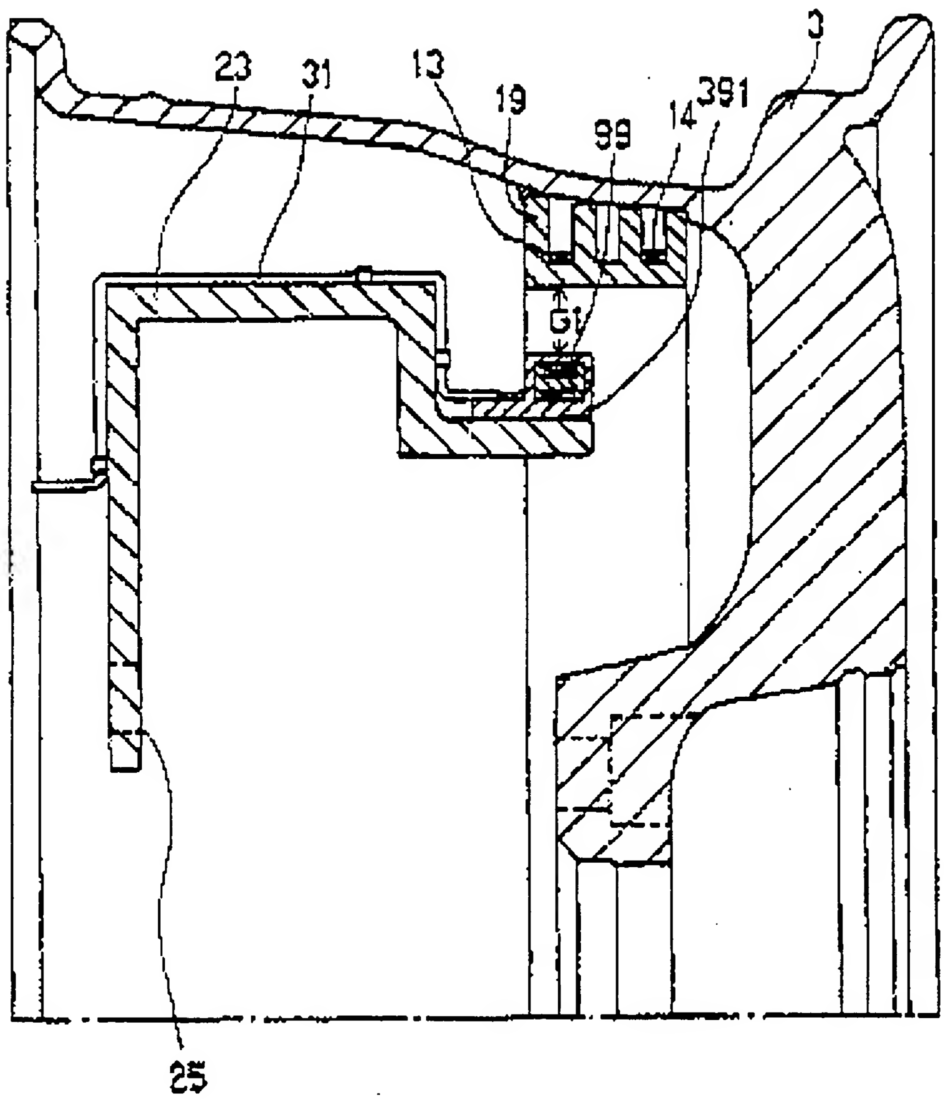


FIG.33

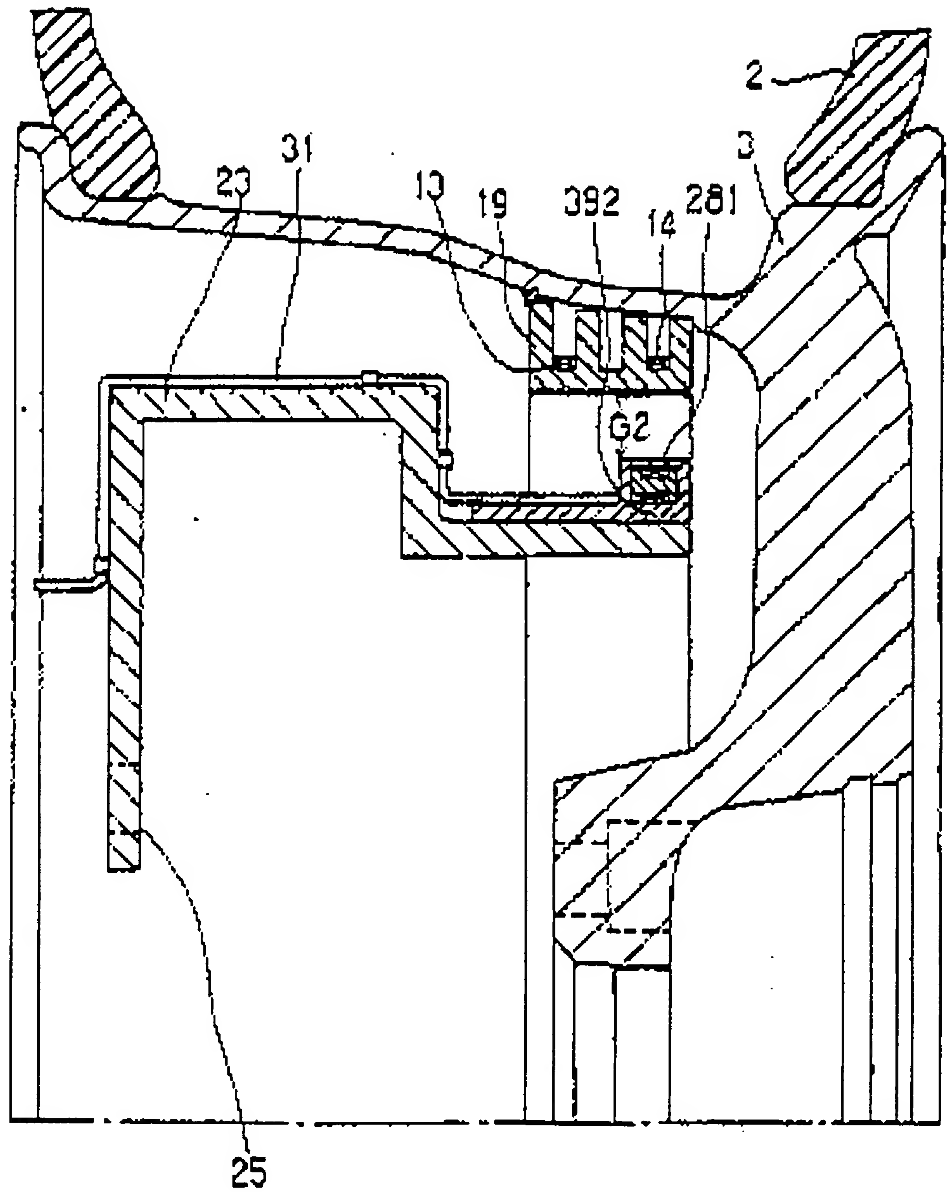


FIG.34(a)

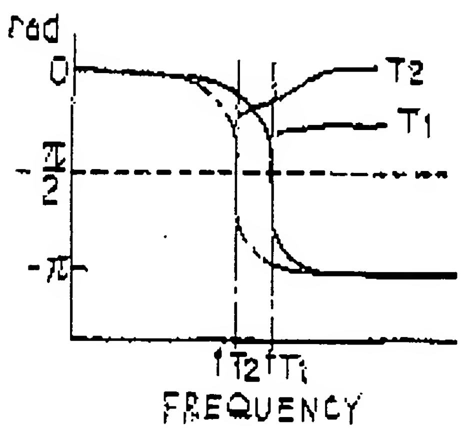


FIG.35(a)

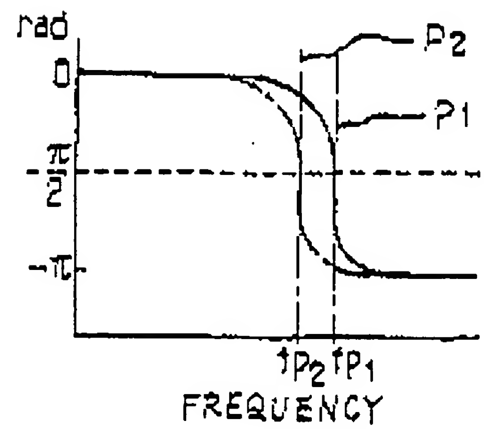


FIG.34(b)

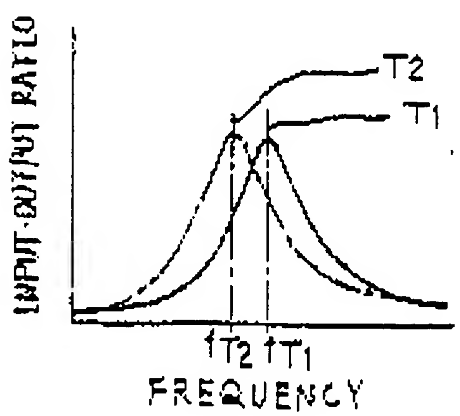


FIG.35(b)

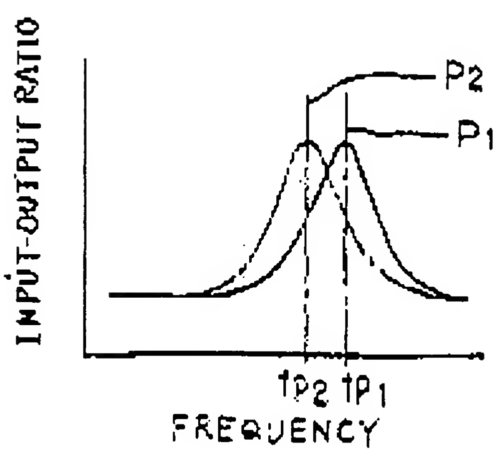


FIG.36

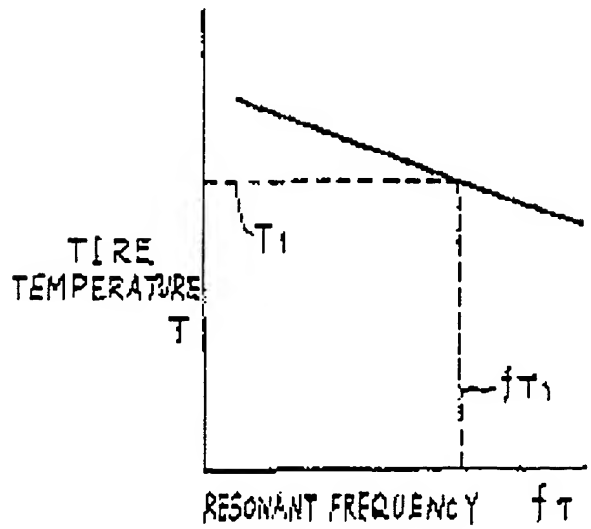

TIRE
TEMPERATURE
T
T1
fT1
RESONANT FREQUENCY fT

FIG.37

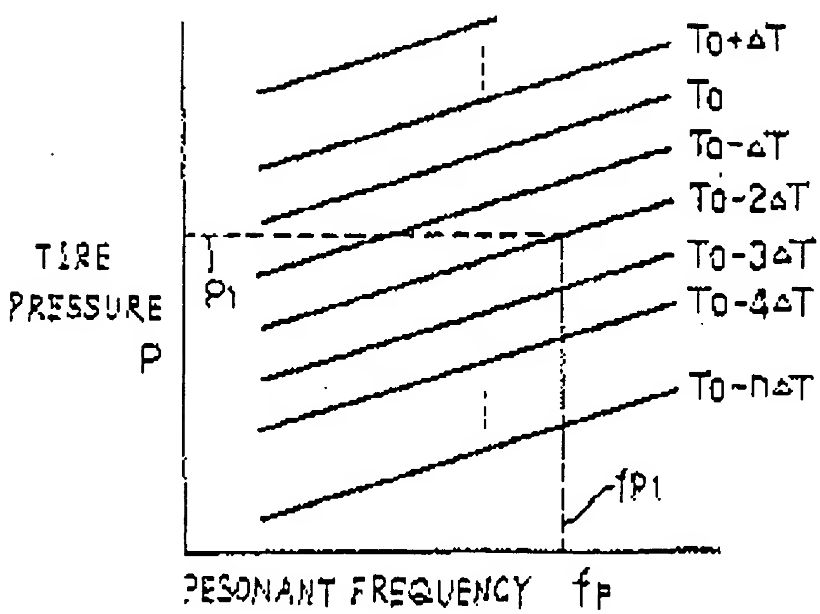

To+ΔT
To
To-ΔT
To-2ΔT
To-3ΔT
To-4ΔT
To-nΔT
TIRE
PRESSURE
P
P1
fP1
RESONANT FREQUENCY fP

FIG.38

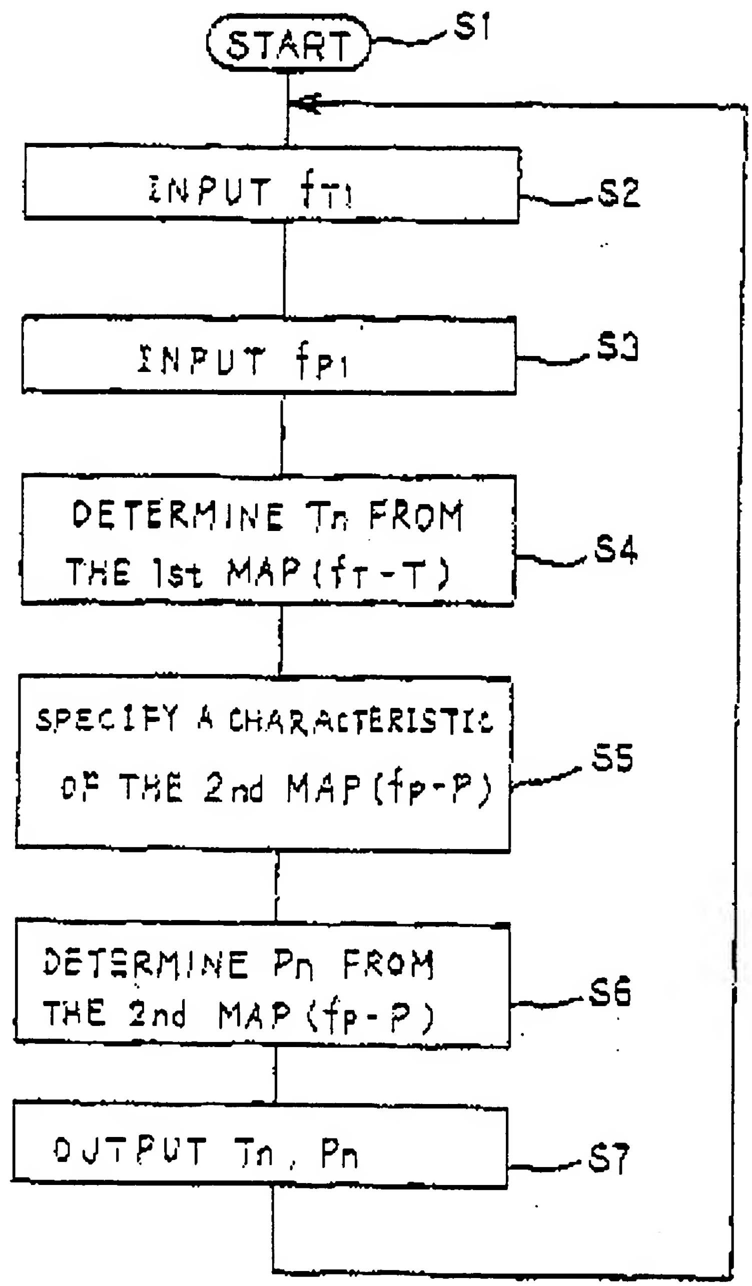

START
S1
INPUT fT1
S2
INPUT fP1
S3
DETERMINE Tn FROM THE 1st MAP (fT - T)
S4
SPECIFY A CHARACTERISTIC OF THE 2nd MAP (fP - P)
S5
DETERMINE Pn FROM THE 2nd MAP (fP - P)
S6
OUTPUT Tn , Pn
S7

FIG.39

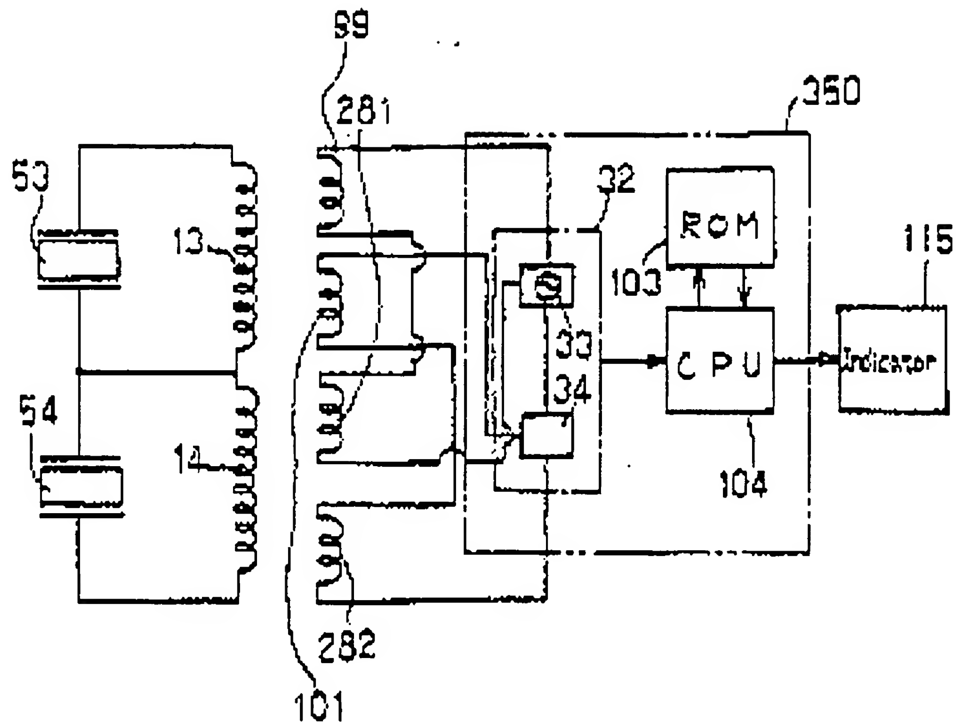

99
281
350
53
32
ROM
13
103
115
33
CPU
Indicator
34
54
14
104
282
101

FIG.40

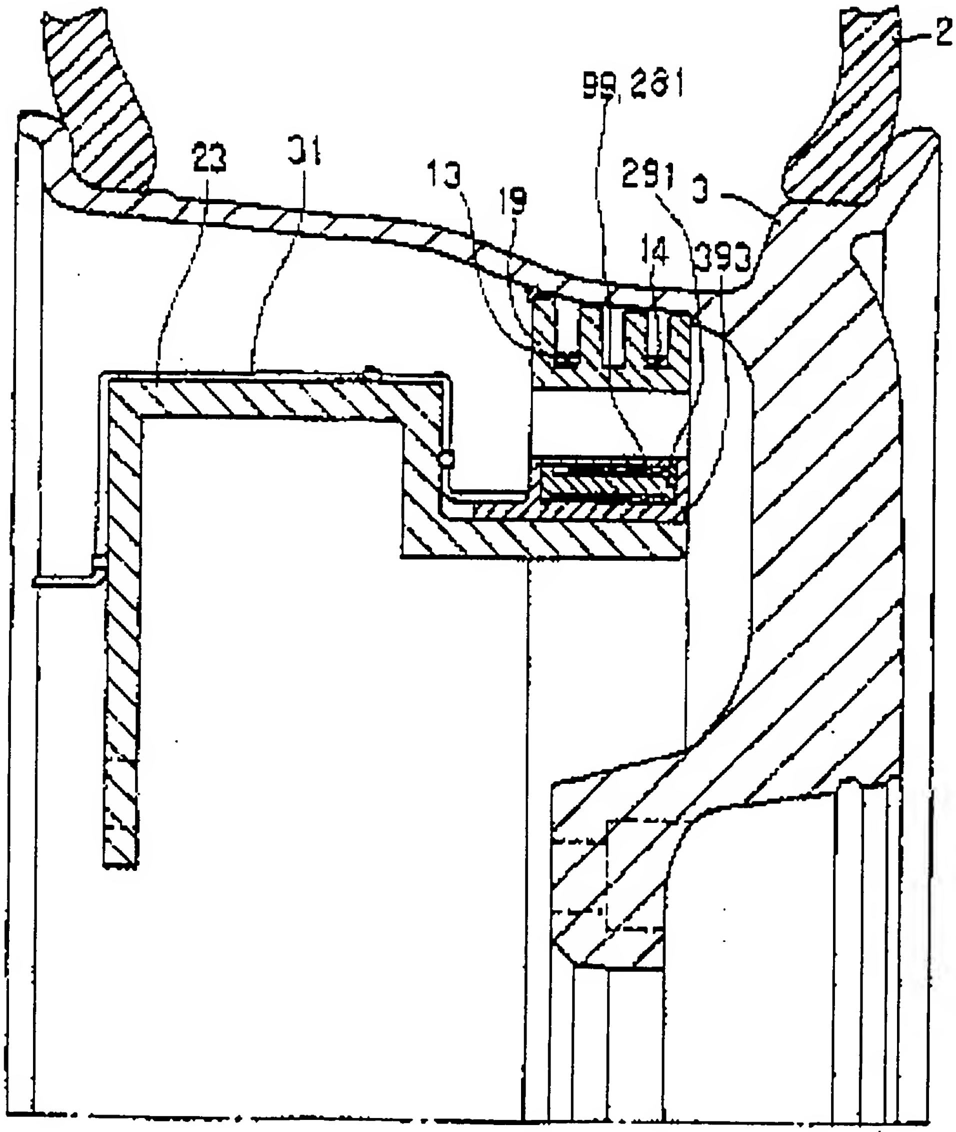


FIG. 41(a)

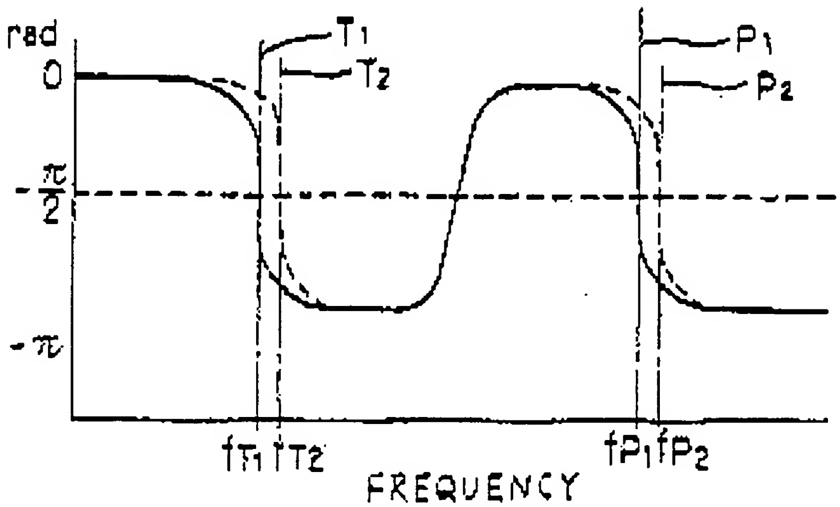


FIG. 41(b)

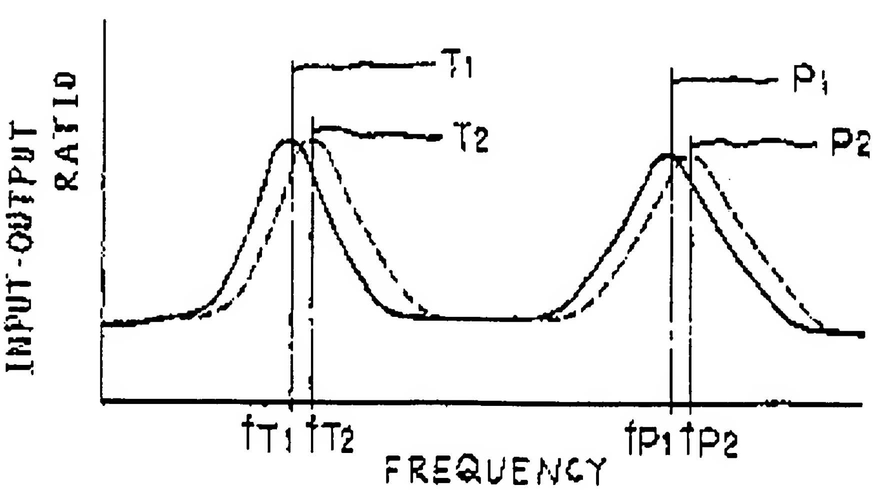


FIG.42

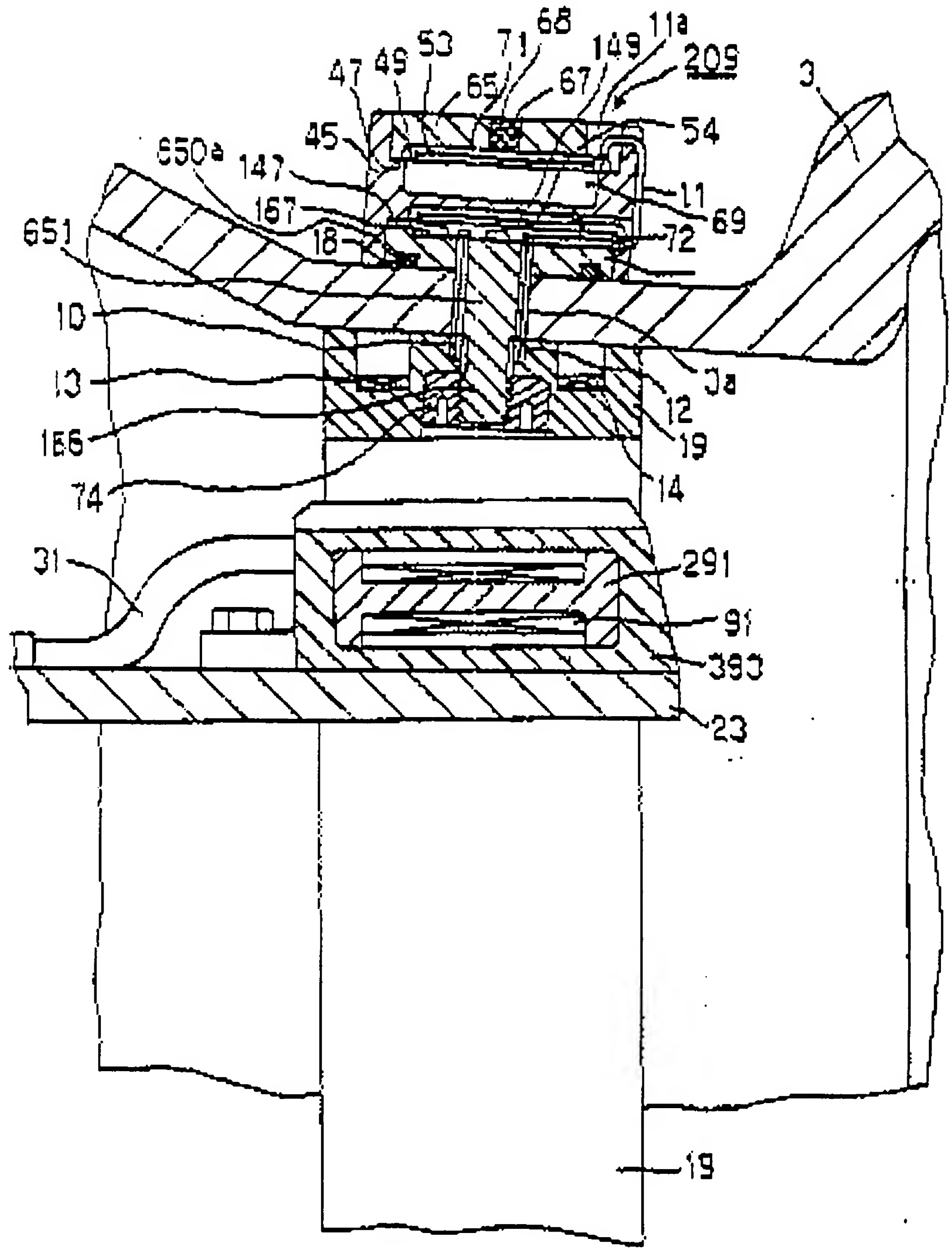

3
209
11a
149
68
71
67
65
53
49
47
45
54
650a
147
11
69
167
72
651
18
10
3a
13
12
19
166
14
74
31
291
91
393
23
19

FIG.43

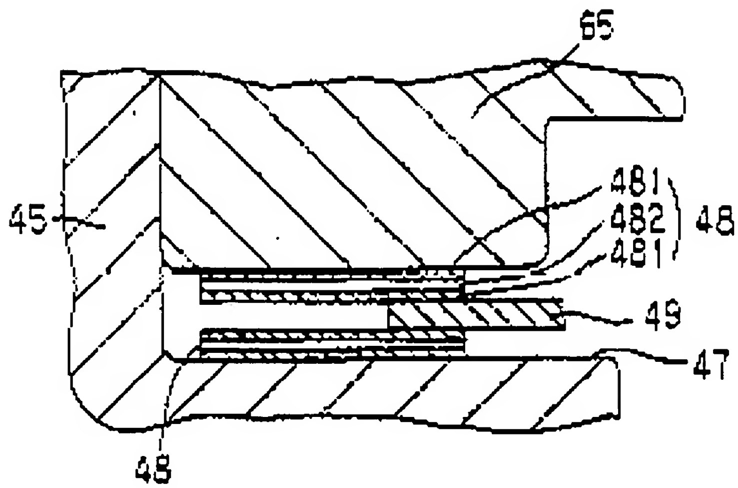


FIG.47

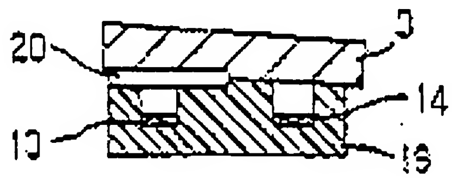


FIG.44

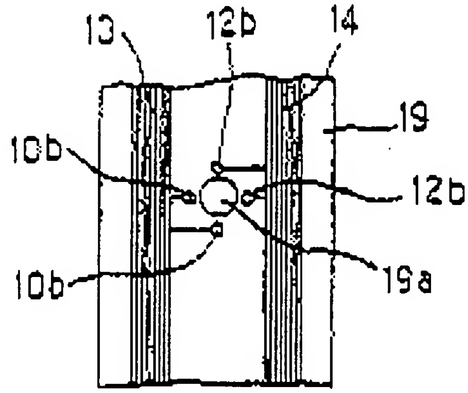


FIG.45

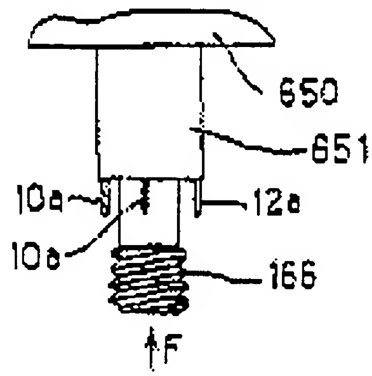


FIG.46

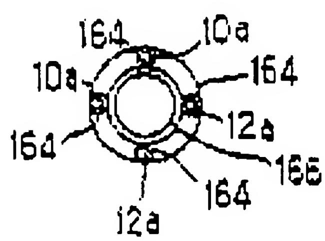


FIG.48

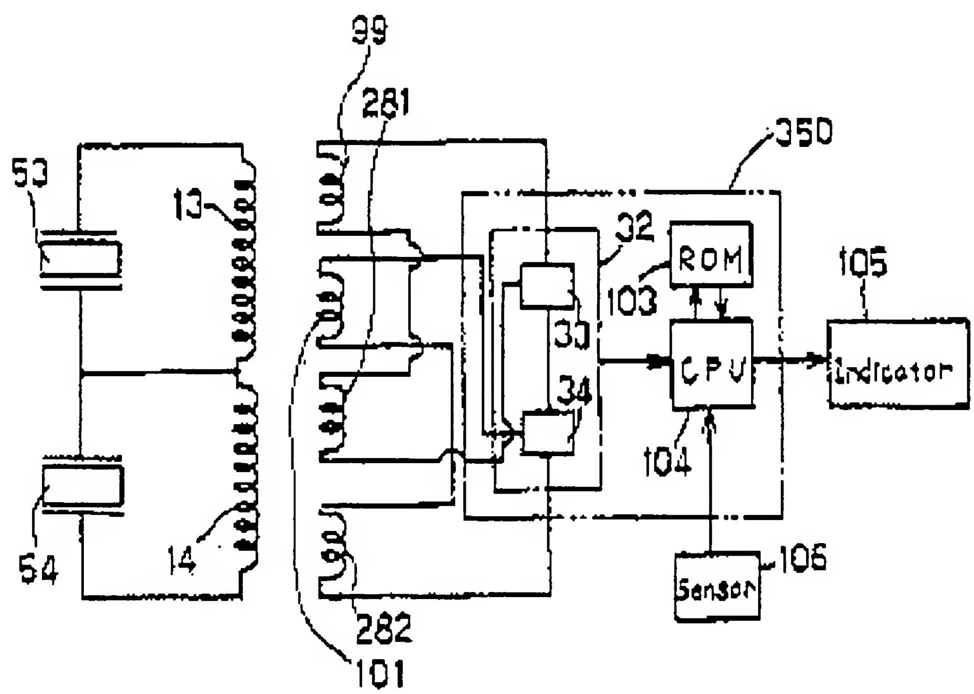

99
281
350
53
13
32
ROM
103
105
33
CPU
Indicator
34
104
54
14
106
Sensor
282
101

FIG.49

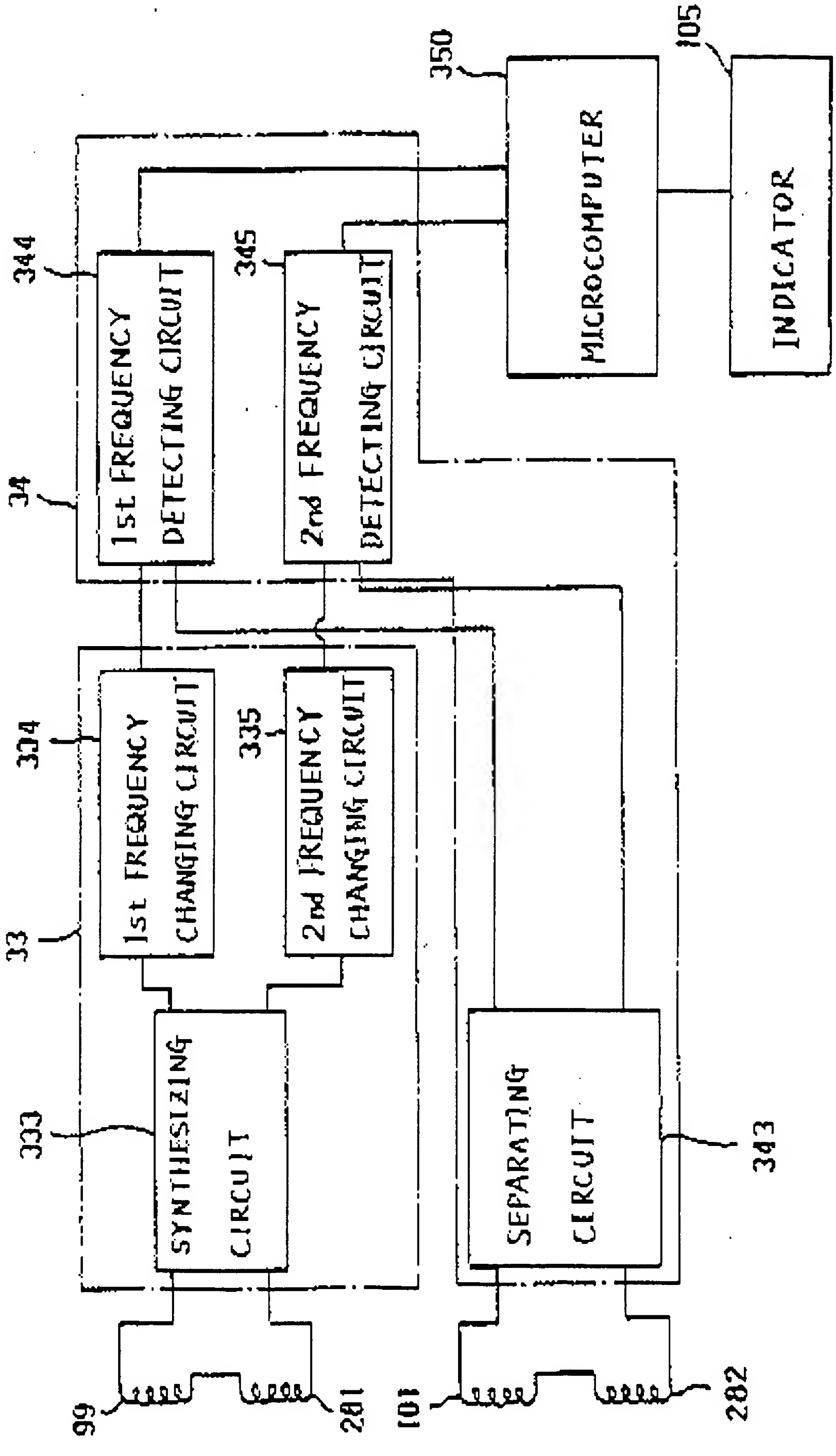

1st FREQUENCY DETECTING CIRCUIT
2nd FREQUENCY DETECTING CIRCUIT
MICROCOMPUTER
INDICATOR
1st FREQUENCY CHANGING CIRCUIT
2nd FREQUENCY CHANGING CIRCUIT
SYNTHESIZING CIRCUIT
SEPARATING CIRCUIT
344
345
34
350
105
334
335
33
333
343
99
281
101
282

FIG.50

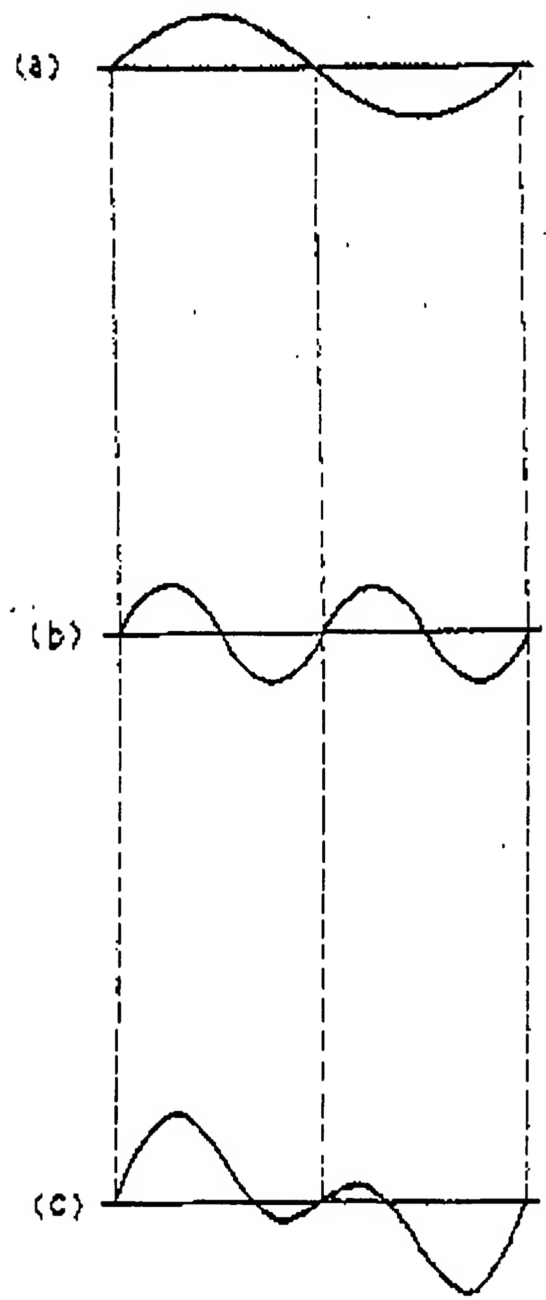


FIG.51

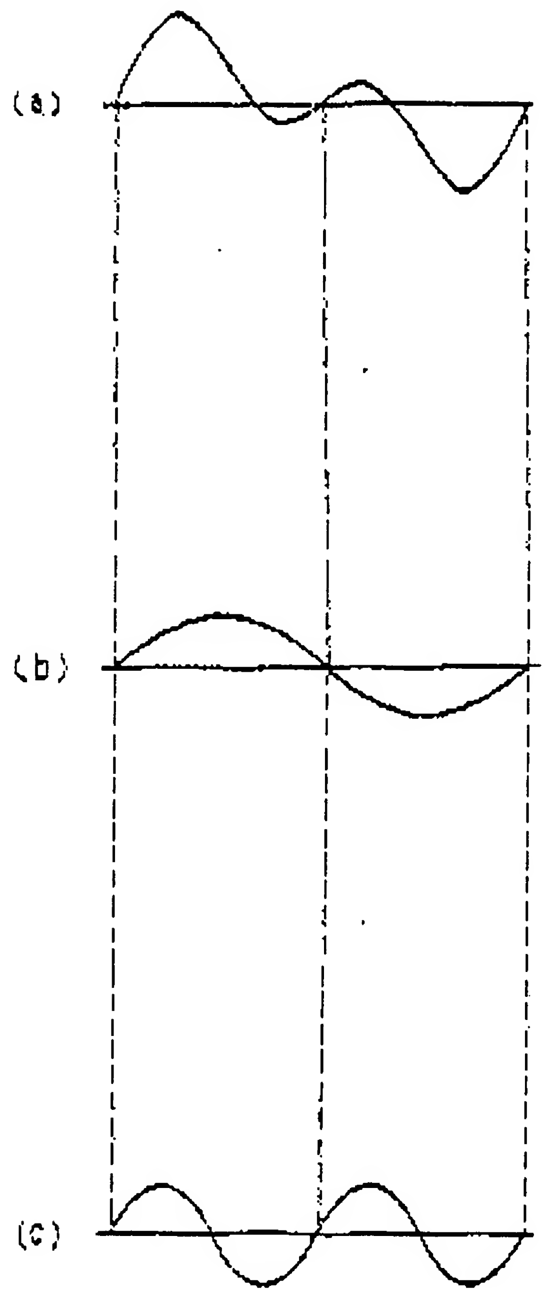


FIG.52

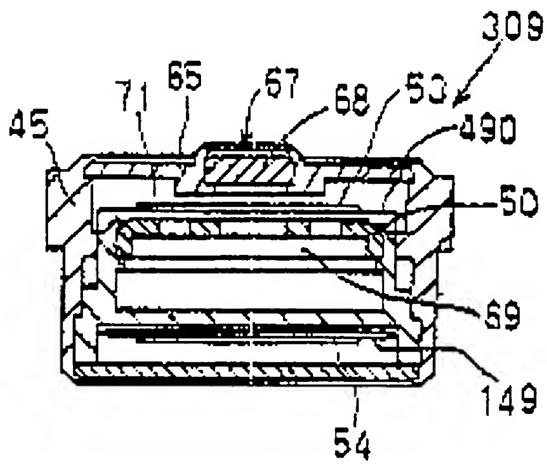
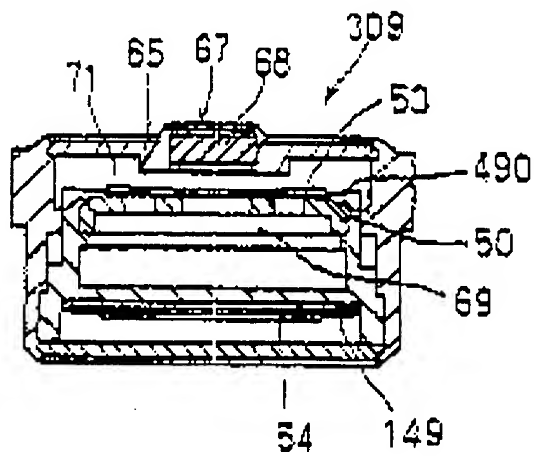

309
71
65
67
68
53
490
45
50
69
149
54

FIG.53


309
65
67
68
71
53
490
50
69
54
149

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European Patent Office
Office européen des brevets

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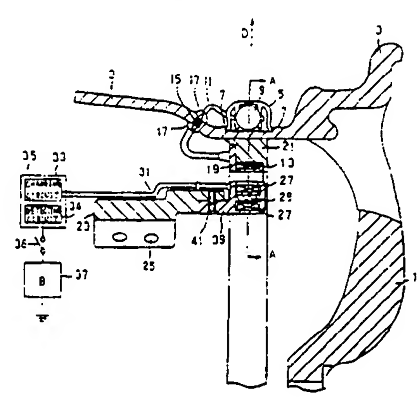
(54) **Tire pressure detecting apparatus for vehicle.**

(57) A tire pressure detecting portion includes a housing, provided within the tire, within which a piezoelectric element is provided so as to be deformed by the tire pressure, whereby the capacity of said piezoelectric element is changed in accordance with its deformation. The piezoelectric element is electrically connected with a first coil disposed within said tire. The first coil (13) is electromagnetically coupled with an excitation coil and a receiving coil, both of which are provided in the vehicle. The excitation coil is electrically connected with an oscillator for supplying the excitation coil with an excitation voltage whose frequency is changed with a predetermined range including a resonant frequency. The receiving coil is electrically connected with resonant frequency determining means. The resonant frequency determining means determines that the received voltage has the resonant frequency. As a result of such determination, pressure determining means determines the corresponding tire pressure based on a data map showing the relationship between said resonant frequency and said tire pressure.

FIG. 1



EP 0 450 653 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 10 5437

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	GB-A-2 122 757 (PRECISION MECHANIQUE LABINAL) * page 4, line 101 - line 120; figures 8-10 *	1,2,9	B 60 C 23/04 B 60 C 23/20
A		20	
Y	EP-A-0 202 375 (GALASKO)	1,2,9	
A	EP-A-0 341 226 (SCHRADER) * column 5, line 21 - column 6, line 25; figure 1A *	3,4,9	
A	WO-A-8 700 127 (MICHELIN) * claims 10,11 *		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

B 60 C

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	10 December 91	HAGEMAN L.M.

CATEGORY OF CITED DOCUMENTS

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Y: particularly relevant if combined with another document of the same catagory
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P: intermediate document
T: theory or principle underlying the invention

E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document